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Final
Report

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Space Station Integrated Propulsion and Fluid Systems Study

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MARTIN MARIETTA

MCR-88-539

Space Station Integrated Propulsion and Fluid Systems Study

Final Report

Contract No. NAS8-36438

September 1988

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FOREWORD

This report was prepared by Martin Marietta Space Systems Company under Contract NAS8-36438 in compliance with the Statement-of-Work. The contract is being administered by Marshall Space Flight Center, Huntsville, Alabama. Mr. John Cramer is the NASA Project Manager. Initial program results were published in metric units in compliance with the Statement-of-Work. During the second phase of the program, a directive was issued by Dale Meyers from NASA Headquarters that all Space Station work would be performed in English units. Consequently, the results from the second phase of the program were published in English units.

SUMMARY

Major benefits can be gained by integrating the Space Station propulsion and fluid systems configurations beyond the Phase B Work Package definitions. This was the most significant conclusion reached during the Space Station Integrated Propulsion and Fluids System Study. Martin Marietta Astronautics Group performed the Integrated Fluids Study for the Space Station Program Office through Marshall Space Flight Center to evaluate the commonality and integration of propulsion and fluid systems associated with the Space Station elements. The Space Station elements consist of the core station and associated vehicles, platforms, experiments and payloads. This includes the NSTS Shuttle, the Orbital Maneuvering Vehicle (OMV), the Orbital Transfer Vehicle (OTV), and the Manned Maneuvering Unit (MMU), co-orbiting platforms in the station orbit, polar platforms, attached modules such as the Japanese Experiment Module (JEM) and satellites and free-flyers that are serviced out of the Space Station.

The program study was performed in two tasks: Task 1 addressed propulsion systems and Task 2 addressed all fluid systems associated with the Space Station elements, which also included propulsion and pressurant systems. Program results indicated a substantial reduction in life cycle costs through integrating the the oxygen/hydrogen propulsion system with the environmental control and life support system, and through supplying nitrogen in a cryogenic gaseous supercritical or subcritical liquid state. A water sensitivity analysis showed that increasing the food water content would substantially increase the amount of water available for propulsion use and in all cases, the implementation of the BOSCH CO2 reduction process would reduce overall life cycle costs to the station and minimize risk.

An investigation of fluid systems and associated requirements revealed a delicate balance between the individual propulsion and fluid systems across work packages and a strong interdependence between all other fluid systems. To ensure that the integration of these systems propel the individual work packages, an independent team to continually assess the direction of the fluid systems designs should be initiated at NASA Level II Headquarters.

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List of Acronyms

ACS	Atmosphere Control and Supply
CFES	Continuous Flow Electrophoresis in Space
CIX	Continuous Ion Exchange (Synonym for Electrodeionization)
ECLSS	Environmental Control and Life Support System
EEU	Extra-vehicular Excursion Unit
ELM	Experimental Logistics Module
ESA	European Space Agency
EVA	Extra-vehicular Activity
°F	Degrees Fahrenheit
FDS	Fire Detection and Suppression
FMS	Fluid Management System
FTIR	Fourier Transform Infrared (Spectrometer)
HFM	Hollow Fiber Membrane
HSD	Hamilton Standard Division of United Technologies
IFMS	Integrated Fluid Management System
IOC	Initial Operational Capability
INS	Integrated Nitrogen System
IR&D	Independent Research and Development
ITCS	Internal Thermal Control System
IVA	Intra-vehicular Activity
IWFS	Integrated Waste Fluid System
IWS	Integrated Water System
JEM	Japanese Experimental Module
KOH	Potassium Hydroxide
LHe	Liquid Helium
MDAC	McDonnell Douglas Astronautics Company
MEOP	Maximum Expected Operating Pressure
MF	Multifiltration
MLI	Multi-Layer Insulation
MMU	Manned Maneuvering Unit
MSFC	(George C.) Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PLC	Pressurized Logistics Carrier
PMMS	Process Materials Management System
PPV	Portable Pressure Vessel
PWHS	Process Waste Handling System
QD	Quick Disconnect
RMS	Remote Manipulator System
SEM	Scanning Electron Microscope
SIRTF	Space Infrared Telescope Facility
SS	Space Station
SSP	Space Station Program
TCS	Thermal Control System
TED	Thermoelectric Device
ULC	Unpressurized Logistics Carrier
USL	United States Laboratory
UV	Ultraviolet
WM	Waste Management
WQM	Water Quality Monitor

1.0 INTRODUCTION

Martin Marietta Astronautics Group has completed a study to provide the Space Station Program Office through NASA Marshall Space Flight Center with an evaluation of commonality and integration of propulsion and fluid systems associated with the Space Station elements. The Space Station elements consist of the core station and associated vehicles, platforms, experiments and payloads. This includes the NSTS Shuttle, the Orbital Maneuvering Vehicle (OMV), the Orbital Transfer Vehicle (OTV), and the Manned Maneuvering Unit (MMU), co-orbiting platforms in the Station orbit, polar platforms, attached modules such as the Japanese Experiment Module (JEM) and satellites and free-flyers that are serviced out of the Space Station.

The study program was broken into two tasks: Task 1 addressed propulsion systems, and Task 2 addressed all fluid systems associated with the Space Station elements, which also included propulsion and pressurant systems. The program logic chart, showing the flow and interrelationship of the tasks performed is presented in Figure 1.0-1.

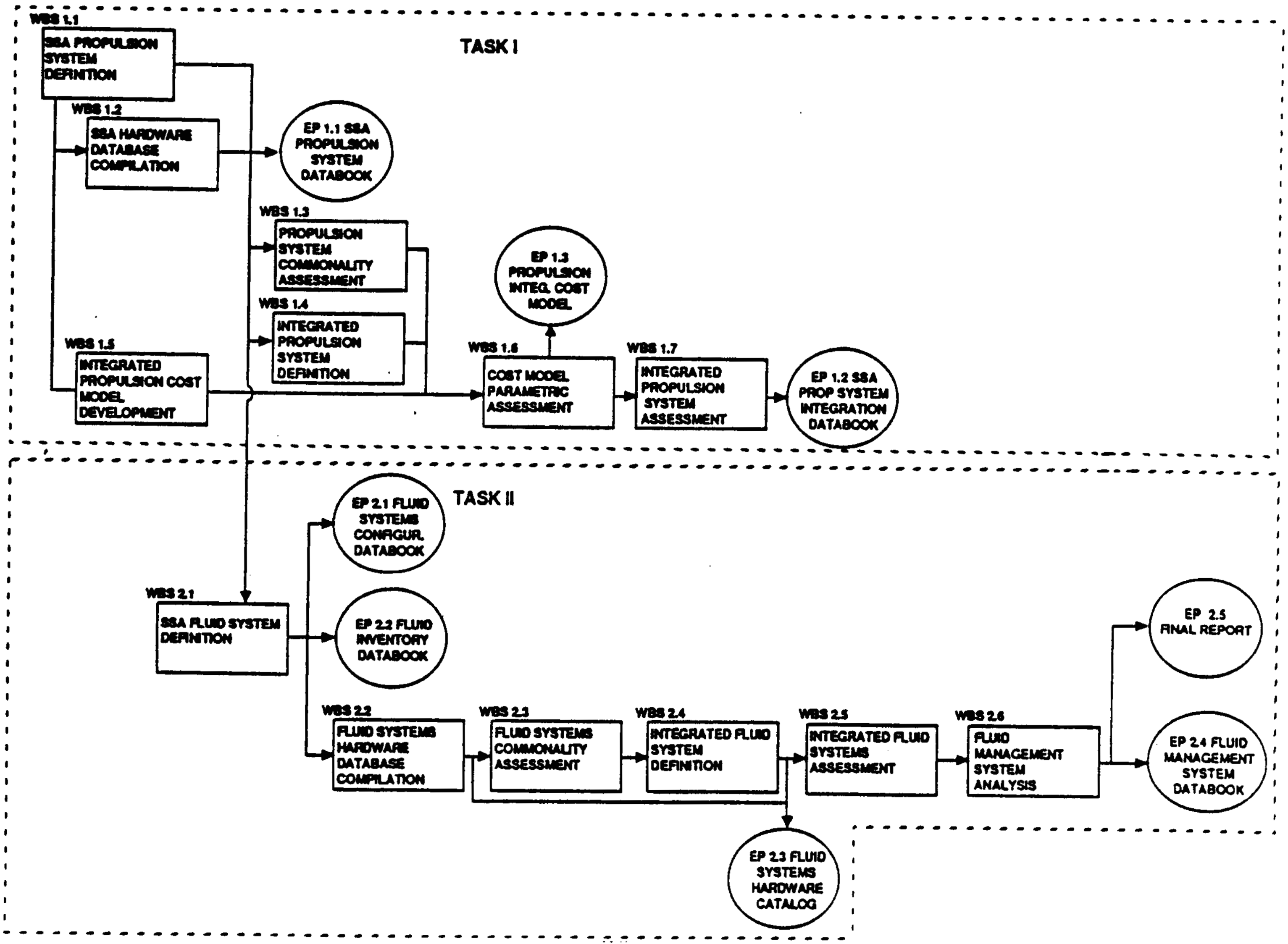

Figure 1.0-1 Program Logic Flow

Task 1 investigated aspects of the Space Station program elements for commonality and integration potential among the various propulsion elements. The objective was to provide data that allowed adequate consideration of cost-effective integration of propulsion elements for the entire Space Station program. This task was divided into seven subtasks and resulted in the preparation of three databooks. The first databook, EP 1.1 "Space Station Architecture Configuration Databook[1]", documented the current status of the propulsion elements as of October 1986. The second databook, EP 1.2," Propulsion/Propellant Systems Integration Databook[2]" documented the implications of Space Station propulsion systems integration. This included the benefits and detriments of integration, methods and means of integration and methods and analysis of integration options considered. A catalog of available and required components was prepared as a part of the second databook. A comprehensive cost model was also prepared and used in making cost assessments that support trade studies documented in EP 1.2. Documentation of the cost model constituted a third databook, the "Integrated Propulsion and Fluids System Cost Model[3]." This cost model was also delivered to MSFC.

Task 2, the Fluids Systems Integration task examined all of the fluid systems that were identified by the Phase B contractors as being part of the IOC and growth Space Station Architecture including the propulsion systems from Task I effort. The objective of this task was to provide an independent assessment of the requirements and design of these systems to determine areas of commonality and potential integration for Space Station elements. This task was divided into five subtasks. During the first task, WBS 2.1 Space Station Program Fluid Systems Definition, information was compiled from the DR-O2 Databooks from Work Package 1 and October 1986 Fluid Technical Interchange Panel Data and documented in databooks, EP 2.1, the " Fluid Systems Configuration Databook[4]" and EP 2.2, the "Space Station Program Fluid Inventory Book[5]." Task 2.2 focused on the generation of a fluid system hardware database similar to the propulsion system hardware database generated in Task 1. This database was used in our commonality assessments to identify unique components that had been called out in the fluid systems designs requiring further technology development. The third major subtask in Task 2, WBS 2.3, was a commonality assessment of the fluid systems. In this subtask, hardware was identiified that could potentially be used by more than one fluid system. The Integrated Fluid Systems Definition Task, WBS 2.4, brought data from Tasks 1 and 2 together for definition of the integrated fluid systems. Integration criteria were established whereby the defined fluid systems were assessed and then documented in EP 2.4, the "Fluids Management System Databook[6]." Key issues associated with the Integrated Water, Nitrogen and Waste Systems were also investigated and considered in the fluid system assessment.

A superscript denotes a reference documented in Section 6.0 of this report.

2.0 TASK 1 - PROPULSION SYSTEMS INTEGRATION

2.1 SPACE STATION ARCHITECTURE PROPULSION SYSTEM DEFINITION

The initial effort on the program was spent documenting the current status of the various propulsion systems in the Space Station Architecture. Requirements and system descriptions for all of the Space Station propulsion system elements and options were gathered, compiled and documented in a contract end item EP 1.1, "Space Station Architecture Propellant Systems Databook." The databook includes baseline propulsion system descriptions, fluid and operational requirements, schematic diagrams and component lists for the following elements: the core station; with and without resistojets, the Orbital Maneuvering Vehicle, a representative configuration for free-flyers, and the satellite servicers. Examples of the fluid system requirements, schematics and component lists are presented in Tables 2.1-1 and 2.1-2 and Figure 2.1-1.

Table 2.1-1 Fluid System Requirements for the Space Station Propulsion System

REQUIREMENT	SIZING		LOGISTICS	
REBOOST	3,800,000		980,000/NOTE 1	
NORMAL REBOOST		980,000		980,000
2-SIGMA REBOOST		2,820,000		0
CONTINGENCY REBOOST	408,000		49,000	
COLLISION AVOIDANCE		310,000		NOTE 2
10% RESERVE		98,000		49,000
REBOOST SUBTOTAL	4,208,000	4,208,000	1,029,000	1,029,000
NORMAL ACS	663,000		663,000	
MOMENTUM MANAGEMENT				
ROLL		44,000		44,000
YAW		209,000		209,000
TRANSIENTS				
BERTHING		116,000		116,000
OTHER		294,000		294,000
CONTINGENCY ACS	1,245,000		0/NOTE 2	
CMG FAILURE				
11-DAYS ROLL		142,000		NOTE 2
11-DAYS PITCH		845,000		NOTE 2
22-DAYS YAW		209,000		NOTE 2
CMG REPAIR		49,000		NOTE 2
ACS SUBTOTAL	1,908,000	1,908,000	663,000	663,000
TOTAL IMPULSE	6,116,000		1,692,000	

NOTE - ALL IMPULSES ARE IN N-S

NOTE 1 - THIS IS AN AVERAGE FOR 90 DAYS OVER A 10 YEAR PERIOD.

NOTE 2 - THESE ARE TOTAL CONTINGENCIES REQUIRED APPROXIMATELY FOUR TIMES WITHIN THE 10 YEAR PERIOD. THEY HAVE BEEN INCLUDED IN THE 90 DAY TANK SIZING REQUIREMENTS.

Table 2.1-2 Fluid Systems Component List for the Oxygen/Hydrogen Propulsion System

ITEM	COMPONENT TYPE	QUAN REQD	SIZE (cm)	PRESSURE MEOP (kPa)	USAGE (MEDIA)	APPROX MASS (kg)	REMARKS
1	Pressure vessel	1	54.1 ID sphere	20691 Operating	GH2	59.0	Composite
2	Pressure vessel	1	38.4 ID sphere	20691 Operating	GO2	36.3	Composite
3	Valve - solenoid, latching	5	0.64	20691 Operating	GH2	0.5	Max flowrate 0.009 kg GH2/sec
4	Valve - solenoid, latching	5	0.64	20691 Operating	GO2	0.5	Max flowrate 0.045 kg O2/sec
5	Regulator - const pressure	3	0.64	20691 in /1379 out	GH2	0.9	Flowrate matches item 3
6	Regulator - const pressure	3	0.64	20691 in /1379 out	GO2	0.9	Flowrate matches item 4.
7	Filter	5	0.64	20691 Operating	GH2	0.5	25 micron nominal filtration
8	Filter	5	0.64	20691 Operating	GO2	0.5	25 micron nominal filtration
9	Thruster - biprop	9	0.64	1379 inlet	GO2/GH2	0.8	110N Redundant Thrust Chamber
10	Valve - vent/relief	1	1.27	22415 set point	GH2	0.8	Controllable vent/auto relief
11	Valve - vent/relief	1	1.27	22415 set point	GO2	0.8	Controllable vent/auto relief
12	Transducer - pressure	1	0.64	0-24140	GH2	0.2	
13	Transducer - pressure	1	0.64	0-24140	GO2	0.2	

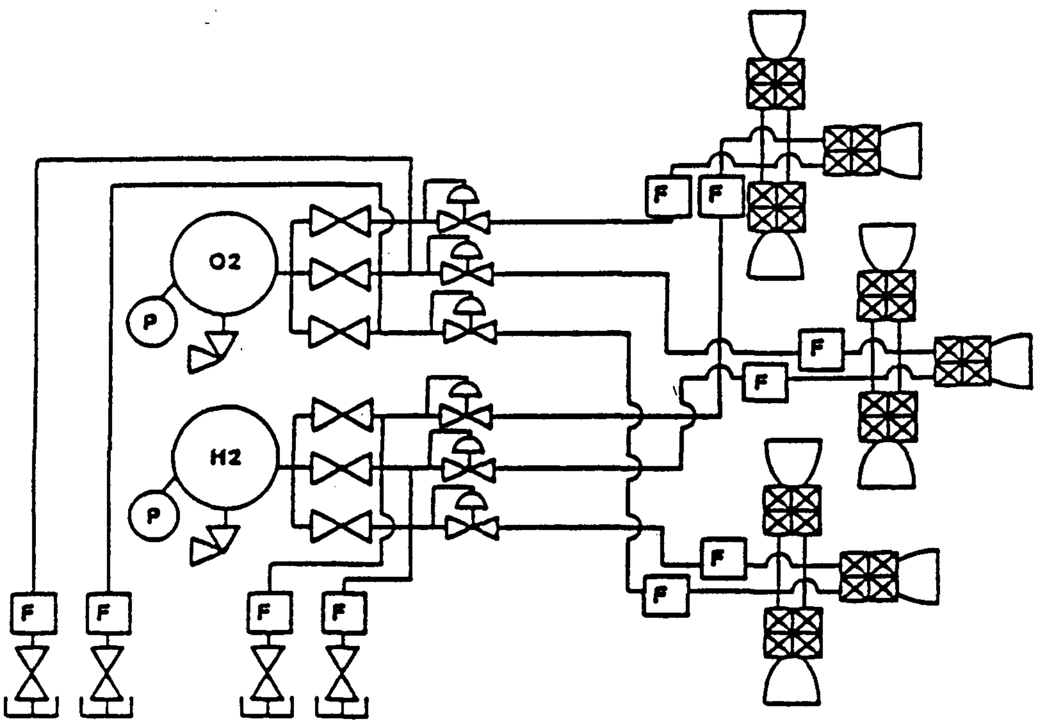

Figure 2.1-1 Schematic of the Oxygen/Hydrogen Propulsion System

2.2 HARDWARE DATABASE COMPILATION

As a parallel effort, information from existing in-house databases and component suppliers was gathered and assembled into a catalog of applicable qualified propulsion system hardware. The catalog includes a list of hardware requirements identified from the previous task. These basic hardware lists were compiled into a database to perform hardware commonality assessments. The hardware catalog was documented in EP 1.2, "Propulsion/Propellant Systems Integration Databook". Components are listed by propulsion system, component type and by the type of fluid/media the component is capable of handling. The components are cross-referenced between the three listings. A detailed description of each of the components is also provided. An example of a component listing by component type and a detailed component description are provided in Tables 2.2-1 and 2.2-2.

2.3 HARDWARE COMMONALITY ASSESSMENT

The previously developed hardware database provided the basis for a hardware commonality assessment. Specific requirements for each component were reviewed and compared with other components having similar requirements. Components identified for multiple use among the propulsion systems during the propulsion system definition task were listed and documented into EP 1.2, the "Propulsion/Propellant Systems Integration Databook". Assessment results showed that major benefits could be gained by using common hardware across Space Station elements by providing greater flexibility for future growth and reducing the number of spare parts in addition to reducing life cycle costs.

2.4 INTEGRATED COST MODEL DEVELOPMENT

A computerized cost model was developed in TURBO PASCAL to perform a comparative cost assessment between various integrated fluid system candidates. The model was developed on IBM PC compatible machines and was uploaded to VAX 11/785 prior to delivery. The use of and information associated with the model was documented in a user's manual to be provided to the Marshall Space Flight Center. Two verification runs comparing the O2/H2 propulsion system alone with an O2/H2 propulsion system with resistojets were included as part of the documentation. The approach used during the model development was similar to the approach used for the Space Station, Orbital Maneuvering Vehicle and Advanced Orbital Transfer Vehicle Programs. The effort of this task was documented in EP 1.3 "Propulsion/Propellant System Integrated Cost Model."

2.5 INTEGRATED PROPULSION SYSTEM ASSESSMENT

An assessment was made to determine the benefits and detriments of an integrated propulsion system compared to an independent propulsion system. Two Space Station Propulsion Systems were evaluated in this study. They were an independent O_2/H_2 propulsion system and an O_2/H_2 propulsion system integrated with a waste gas resistojet. Both systems use a water electrolysis system as their primary source of oxygen and hydrogen. Water is supplied to the electrolysis system from two sources, the Space Station Integrated Water System (IWS) and the NSTS Shuttle fuel cells. In this study, the water from these sources is assumed to be free waste water and, therefore, no charge has been assessed for propellant. In addition, this study assumes a waste fluid system is available for both systems and, therefore, no cost is shown for its design and construction.

Parameters evaluated in the assessment were: cost, commonality, reliability, maintainability, safety, contamination, technological risk, growth potential, and flexibility. The findings of these assessments are included in the following paragraphs.

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Table 2.2-1 Component Listing by Component Type

COMPONENT TYPE	SUB-TYPE	SHEET NO.	ITEM NO.	PROGRAM APPLICATION	USAGE (MEDIA)	MEOP (kPa)	PORT SIZE (cm)	APPROX. MASS (kg)	QUANTITY REQUIRED	VENDOR	VENDOR PART NUMBER
Pressure Vessel	Composite	108	270	SS THKFM	GO2	20691	0.64	163.3	1	TBD	TBD
Pressure Vessel	Composite	109	271	SS THKFM	GO2	20691	0.64	213.1	1	TBD	TBD
Pressure Vessel	Composite	110	272	SS THKFM	GH2	20691	0.64	213.1	1	TBD	TBD
Pressure Vessel	Composite	111	273	SS THKFM	GH2	20691	0.64	226.8	2	TBD	TBD
Pressure Vessel	Composite	112	274	SS THKFM	GH2	20691	0.64	235.8	1	TBD	TBD
Pressure Vessel	Composite	113	275	SS ACS	GO2	20691	0.64	36.3	1	TBD	TBD
Pressure Vessel	Composite	114	276	SS ACS	GH2	20691	0.64	59.0	1	TBD	TBD
Pressure Vessel	Composite	115	277	SS BOOST	GO2	20691	0.64	81.6	1	TBD	TBD
Pressure Vessel	Composite	116	278	SS BOOST	GH2	20691	0.64	113.4	1	TBD	TBD
Pressure Vessel	Spherical, Bladder	117	279	SS OPT I	H2O	414	0.64	90.7	4	TBD	TBD
Pressure Vessel	Spherical, Bladder	117	281	SS OPT II	H2O	414	0.64	90.7	4	TBD	TBD
Pressure Vessel	Spherical, Bladder	117	282	SS OPT III	H2O	2069	0.64	90.7	4	TBD	TBD
Pressure Vessel	Spherical, Bladder	117	283	SS OPT IV	H2O	2069	0.64	90.7	4	TBD	TBD
Pressure Vessel	P.D. Bellows	118	280	SS OPT I	H2O	20691	0.64	13.6	3	TBD	TBD
Pressure Vessel	Composite	119	284	OTV-SB	LO2	690	6.99	45.0	2	TBD	TBD
Pressure Vessel	Composite	119	288	OTV-GB	LO2	690	6.99	45.0	2	TBD	TBD
Pressure Vessel	Composite	120	285	OTV-SB	LH2	690	6.99	68.0	2	TBD	TBD
Pressure Vessel	Composite	120	289	OTV-GB	LH2	690	6.99	68.0	2	TBD	TBD
Pressure Vessel	Composite	121	286	OTV-SB	GO2	6900	1.27	13.6	1	TBD	TBD
Pressure Vessel	Composite	121	287	OTV-SB	GH2	6900	1.27	13.6	2	TBD	TBD
Pressure Vessel	Diaphragm	122	290	OTV-GB	N2H4	2760	1.91	13.6	3	TBD	TBD
Pressure Vessel	Composite	123	291	OMV	GHE	30300	TBD	9.0	4	Structural Composites Indus. Inc.	TBD
Pressure Vessel	Composite	124	292	OMV	MMH	2413	TBD	37.2	2	Pressure Systems Inc.	TBD
Pressure Vessel	Composite	124	293	OMV	N2O4	2413	TBD	37.2	2	Pressure Systems Inc.	TBD
Pressure Vessel	Composite	125	294	OMV	N2H4	3030	TBD	8.1	4	Pressure Systems Inc.	TBD
Pressure Vessel	Composite	126	295	OMV	GH2	24800	TBD	9.5	4	Structural Composites Indus. Inc.	TBD
Pressure Vessel	Composite	127	296	MONO-OSCRS	N2H4	3449	1.91	54.4	3	Pressure Systems Inc.	80263-X

Table 2.2-2 Detailed Component Description

COMPONENT DATA SHEET 104

PRESSURE REGULATOR DATA REPORT / DATA ENTRY DATE: 03/05/87

TYPE...	MECHANICAL
SUBTYPE (INLET OR OUTLET REGULATION).......	OUTLET
MANUFACTURER.................................	001, AERODYNE CONTROLS CORPORATION
MANUFACTURER'S PART NUMBER.................	3066-5-000 MODIFIED
MARTIN MARIETTA PART NUMBER................	-0-
QUALIFICATION STATUS........................	CURRENT
PAST APPLICATIONS...........................	AWACS
PRINCIPAL MATERIAL OF CONSTRUCTION.........	ALLUMINUM ALLOY
SEAL MATERIAL................................	BUTYL
SEAT MATERIAL................................	-0-
UPPER INLET OPERATING PRESSURE (PSIA)......	850.000
LOWER INLET OPERATING PRESSURE (PSIA)......	60.0000
UPPER OUTLET OPERATING PRESSURE (PSIA).....	19.5000 MOD TO 30.00
LOWER OUTLET OPERATING PRESSURE (PSIA).....	-0-
INLET PROOF PRESSURE (PSIG)................	1500.00
OUTLET PROOF PRESSURE (PSIG)...............	750.000
INLET BURST PRESSURE (PSIG)................	3000.00
OUTLET BURST PRESSURE (PSIG)...............	1000.00
MAXIMUM OPERATING TEMPERATURE (F)..........	160.000
MINIMUM OPERATING TEMPERATURE (F)..........	-65.0000
THERMAL CYCLES (CYCLES)....................	-0-
CYCLE TEMPERATURES (RANGE,F)...............	-0-
INLET PORT SIZE (IN).......................	0.25000
OUTLET PORT SIZE (IN)......................	0.25000
PRESSURE DROP (PSID).......................	-0-
FLOW RATE....................................	15 SCFM, MAX
PRESSURE DROP TEST FLUID...................	AIR
Cv (FLOW FACTOR)...........................	-0-
INTERNAL LEAKAGE............................	.0003 SCCS SF6
EXTERNAL LEAKAGE............................	ZERO APPARENT
MAXIMUM CONTAMINATE ALLOWED (MICRONS)......	25.0000
VIBRATION LIMITS (GRMS)....................	6.90000
VIBRATION TIME (MIN/AXIS)..................	-0-
SHOCK LIMITS (G's).........................	15.0000
REGULATION ACCURACY (%)....................	15.0000
WEIGHT (LBF)................................	0.55000
LIFETIME (YEARS)............................	15.0000
CYCLE LIFE (CYCLES).........................	100000.
MTBF (HOURS)................................	-0-
LEAD TIME (WEEKS)...........................	23
COMPATIBLE FLUIDS...........................	20

ENVELOPE..... 3.4 IN X 3.9 IN X 1.75 IN

COMMENTS..... CYCLE LIFE IS ALSO MTBF

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2.5.1 System Description

The following paragraphs provide a physical description of the propulsion systems analyzed. These systems are further described in EP 1.1, "Space Station Architecture Propellant Systems Databook."

2.5.1.1 Space Station O_2/H_2 Propulsion System - The Space Station O_2/H_2 propulsion system consists of four ACS modules and one reboost module. All of these modules use gaseous O_2 and H_2 as propellants, with the O_2 and H_2 produced by water electrolysis. EP 1.1, "Space Station Architecture Propellant System Databook", Section 2.4, presents four possible O_2/H_2 propulsion system configurations that would meet the current Space Station propulsion requirements. Of these four options, the first was a pressurized water feed electrolysis system, which was chosen for this study because the technologies required for its contruction are within the current state of the art. The other three have technology risks that are far greater than those of Option 1. The electrolysis units are located in the Space Station nodes. The gas is piped from the nodes to a tank farm on the central truss structure of the Station for storage. Propellant accumulators are located in the ACS and reboost propulsion modules to provide ready service propellants. These accumulators are refilled from the central tank farm as they become depleted. For this system, all waste fluids on Space Station must be stored in accumulator tanks and returned to Earth.

2.5.1.2 Space Station O_2/H_2 System Integrated with Resistojets - The O_2/H_2 propulsion system plus resistojets consists of the basic O_2/H_2 system as above, but also includes a resistojet reboost module to make use of waste fluids from the Space Station as propellants. The resistojet module cannot be used as a total replacement for the O_2/H_2 reboost module because analysis shows that there is insufficient waste fluid to provide impulse for all reboost contingencies as collision avoidance. Therefore, the O_2/H_2 reboost module has been retained and the resistojet module added to take advantage of the waste fluids that are known to be available on the Space Station. Assuming that all waste gases could be vented, this approach eliminates the need for accumulating the waste fluids and returning them to Earth.

2.5.2 System Assessment

2.5.2.1 Cost - A comparison of propulsion system cost was made for the two candidates using the propulsion system cost model developed in this program. This model computes life cycle costs from propulsion requirements and a detailed system description. The final life cycle costs of the two systems are presented in Table 2.5-1.

Table 2.5-1 Integrated Propulsion System Cost Assessment (Millions of Dollars)

	O_2/H_2	O_2/H_2 + R-JET
Acquisition	209.35	222.92
Launch	29.14	30.08
Assembly	5.09	5.82
IOC Cost	243.58	258.82
Spares	171.16	185.47
Maintenance	12.69	15.02
Waste Deorbit	456.44	-0-
Operating Cost	640.29	200.49
Total Cost	883.87	459.31

The results show that the initial costs of the system without resistojets is less expensive by about \$15 million. However, the cost of adding resistojets can be recovered in less than one year when using the waste fluids as propellant, thereby eliminating the cost of deorbiting those fluids in the NSTS Shuttle (approximately \$41 million per year). The additional spare parts cost and maintenance cost incurred because of the additional module amounts to about another \$17 million over the 11 year life assumed for this scenario.

2.5.2.2 Commonality - Commonality is not a discriminator between the two systems. The level of commonality in the two example systems is quite high due to the modular design of the systems. The ACS propulsion modules are all identical, and the reboost module is different only in the size of the storage accumulators and the orientation of the thrusters. Common components are therefore used throughout both systems. The cost savings associated with common parts are accounted for in the cost model.

2.5.2.3 Reliability - Reliability is not a discriminator because the two propulsion systems examined are designed to be two failure tolerant. This means that for any two component failures there will be no change in Space Station operations. The addition of the resistojet system, since it will not provide the total impulse required for all propulsion contingencies, does nothing to decrease the level of redundancy to which the system must be designed. However, the resistojet system does provide a greater safety margin for the Space Station because, in the event of a total O_2/H_2 system failure, the resistojet system could provide some reboost capability until repairs could be completed.

2.5.2.4 Maintainability - Maintainability presents no discernable difference between systems. Both of the systems included in this study will require maintenance at some point during Space Station life, whether it is due to routine replacement after several years of service or due to replacement of a malfunctioning module. As a conservative estimate the assumption was made that 100 percent spares would be included in the cost of each system, and that each module would be replaced once in the eleven year scenario. The crew time required for replacing each module was assumed to be 8 EVA hours, with additional IVA hours required for routine maintenance checks using diagnostic software or similar means. In addition, ground maintenance time is required for repairs and checkout of repaired modules before relaunching. Because of the different number of modules in the two systems, more maintenance will be required for the integrated system, and this has been accounted for in the cost model.

2.5.2.5 Safety - When viewed as a stand alone discriminator, safety gives a slight edge to the system with resistojets. The safety issues that are relevant to this study include those from system failure, gas leaks, and explosion or fires. The similarity of the two systems eliminates the need to compare most of the possible hazards simply because they are identical for each system. The addition of the resistojet system does, however, change some of the safety concerns. By adding the resistojet system, the need for transporting pressure vessels full of waste gases back to Earth in the NSTS Shuttle is eliminated. Additionally, the increase in total impulse available is increased providing a greater safety margin in the event of a failed O_2/H_2 system.

2.5.2.6 Contamination - Contamination has very little effect on this assessment. Eliminating waste fluids may be accomplished in several ways. Waste gases may be vented through resistojets on a continuous basis, stored for 14 days and then vented to space in small predetermined quantities or if neither of those options are available, stored and taken back to Earth. For this assessment, storage/deorbit was used because of the concern that the constituents of the waste fluids vented to the surrounding environment may exceed column density or deposition requirements. The O_2/H_2 system stores all of its waste fluids and transports them back to Earth. Alternatively, the integrated resistojet system vents waste gas quantities on a continuous basis.

With the exception of a limited viewing area around the resistojet plume, previous studies have shown that this system meets the column density venting requirements for the Space Station program.[7] Therefore contamination cannot be used as a discriminator between the two systems. Deposition requirements of condensible waste quantities on exterior Station surfaces were reexamined in Task 2 and are discussed in greater detail in Section 4.8 of this report.

2.5.2.7 Technical Risk - Both the water electrolysis and resistojet technologies present some risk to completing the propulsion system on time. The technological risks associated with developing the electrolysis propulsion system are by far the most significant in this comparison. The resistojet technology is much more advanced than the water electrolysis technology and, therefore, has no significant impact on the comparison of the these two systems. A question remains as to whether the resistojets are capable of venting the CO_2/CH_4 mixture from the Sabatier CO_2 reduction process in the ECLS system. Venting this mixture at high temperatures (2552 ^oF) may result in carbon deposition in the resistojets. To prevent carbon deposition during venting, the resistojets may be required to operate at inefficiently low temperatures (932 ^oF). Although additional testing will be required to verify the effectiveness of this method, the technical risk for resistojet implementation is not high. As both systems must have electrolysis units, they are equal as far as technological risk.

2.5.2.8 Growth Potential - As the scenario for Space Station growth stands, neither of the two propulsion systems is more advantageous. If the amount of waste gases produced were sharply increased, it might be possible, at some later stage in Space Station life, to use only the resistojet system for reboost, maintaining the O_2/H_2 reboost module only for contingencies and emergencies. This makes the integrated system with resistojets a slightly more attractive candidate.

2.5.2.9 Flexibility - The flexibility of the Space Station Option I plus resistojet system is much greater than that of the Space Station Option I without resistojets. This flexibility comes from adding the very low thrust levels provided by the resistojets. These would allow the Space Station, at least for short periods of time, to operate in a continuous drag makeup mode to avoid creating disturbances of the the Space Station gravity environment. This mode is desirable, if not mandatory, for successful completion of some experiments.

2.5.3 Conclusion

The cost savings associated with using an integrated propulsion system which includes resistojets makes it the more attractive choice. Cost is not the only indicator in choosing the resistojet system. The other factors examined, although their effects are minor, also favor the O_2/H_2 system integrated with resistojets as the current system for the Space Station.

3.0 TASK 2 - FLUIDS SYSTEMS INTEGRATION

3.1 SPACE STATION ARCHITECTURE FLUIDS SYSTEMS DEFINITION

The fluids and fluids systems contained within the Space Station Program Elements were defined by compiling subsystem concepts and requirements from Martin Marietta Space Station elements databases and the Phase B contractors, subcontractors, and NASA Work Package Centers. Space Station Station Program Elements investigated are presented in Table 3.1-1. Fluid system descriptions and system requirements were documented in EP 2.1, " Fluid Systems Configuration Databook" and EP 2.2, "Space Station Program Fluid Inventory Databook."

Table 3.1-1 Space Station Program Elements

United States Laboratory
Habitation Module and Airlocks
Logistics Elements
Japanese Experimental Module
Columbus
Integrated Waste Fluid System
Integrated Water System
Integrated Nitrogen System
Environmental Control and Life Support System
Thermal Control System
Attached Payloads
Fluid Services/Vehicle Accommodations

Each Program Element documented in the "Fluid Systems Configuration Databook" includes a discussion of the overall system requirements, specific fluid systems requirements and system descriptions. The system descriptions contain configurations, fluid inventory data and component lists. In addition, a list of information sources are referenced in conjunction with each element. Examples of the fluid system information provided in EP 2.1, "Fluid Systems Configuration Databook" are presented in Tables 3.1-2 and 3.1-3 and Figure 3.1-1.

Data contained in the "Fluids Systems Configuration Databook" were used to generate EP 2.2, the "Space Station Program Fluid Inventory Databook" which includes fluid inventory data categorized by fluid system and fluid media. Data within each of these categories were tabulated into information associated with fluid quantities, usage rates, resupply requirements and fluid composition, and system interfaces such as line sizes, fluid pressures, and fluid temperatures. Miscellaneous information such as fluid system disposal waste methods and the level of system failure tolerance was also included. Examples of the information included in EP 2.2, the "Space Station Program Fluid Inventory Databook" is presented in Tables 3.1-4 and 3.1-5.

3.2 FLUID SYSTEM HARDWARE DATABASE

Component lists for individual component systems were extracted from the information developed in the "Space Station Program Fluids Systems Definition" task and compiled into EP 2.3, "Space Station Program Fluid Systems Hardware Catalog." The component data was cross-referenced into several categories. Data was listed by fluid system, component type, and by fluid media type. In addition, individual component information sheets were included for

Table 3.1-2 Fluid System Requirements for the Environmental Control and Life Support System

ECLSS Subsystem	Fluid Requirements
Temperature and Humidity Control	1) Cabin air temperature and humidity control. (nominal module temperature range 65°F - 80°F) 2) Intermodule ventilation. 3) Avionics Air Cooling.
Atmospheric Control and Supply	1) O_2/N_2 pressure control a) PPO_2; 2.83 psia to 3.35 psia b) PPN_2; 11.35 psia to 11.87 psia c) Total pressure; 14.7 $\pm$ .2 psia 2) Vent and relief. 3) O_2/N_2 storage and distribution.
Atmospheric Revitalization	1) CO_2 removal through regenerative process. 2) CO_2 reduction (Bosch/Sabatier). 3) O_2 generation (KOH Static Feed). Electrolysis Unit as primary source of O_2. 4) Contaminant control. 5) Contaminant monitoring.
Fire Detection and Suppression	1) Fire detection. 2) Fire suppression. 3) Crew protection.
Water Recovery and Management	1) Potable and hygiene water processing. Collect, process and dispense water to meet crew needs. 2) Urine/flush processing. Process and dispose of urine an fecal matter from crew members. 3) Water storage and distribution. Provide a closed-loop recovery system for potable and hygiene water. (TIMES) 4) Water thermal conditioning. 5) Water quality control and monitoring. Ensure proper water quality through pretreatment, post-treatment, and monitoring.
Waste Management	1) Trash collecting and processing. 2) General housekeeping. 3) Commode and Urinal. 4) Storage of brine, solid carbon, and feces canister in pressurized logistics carrier.

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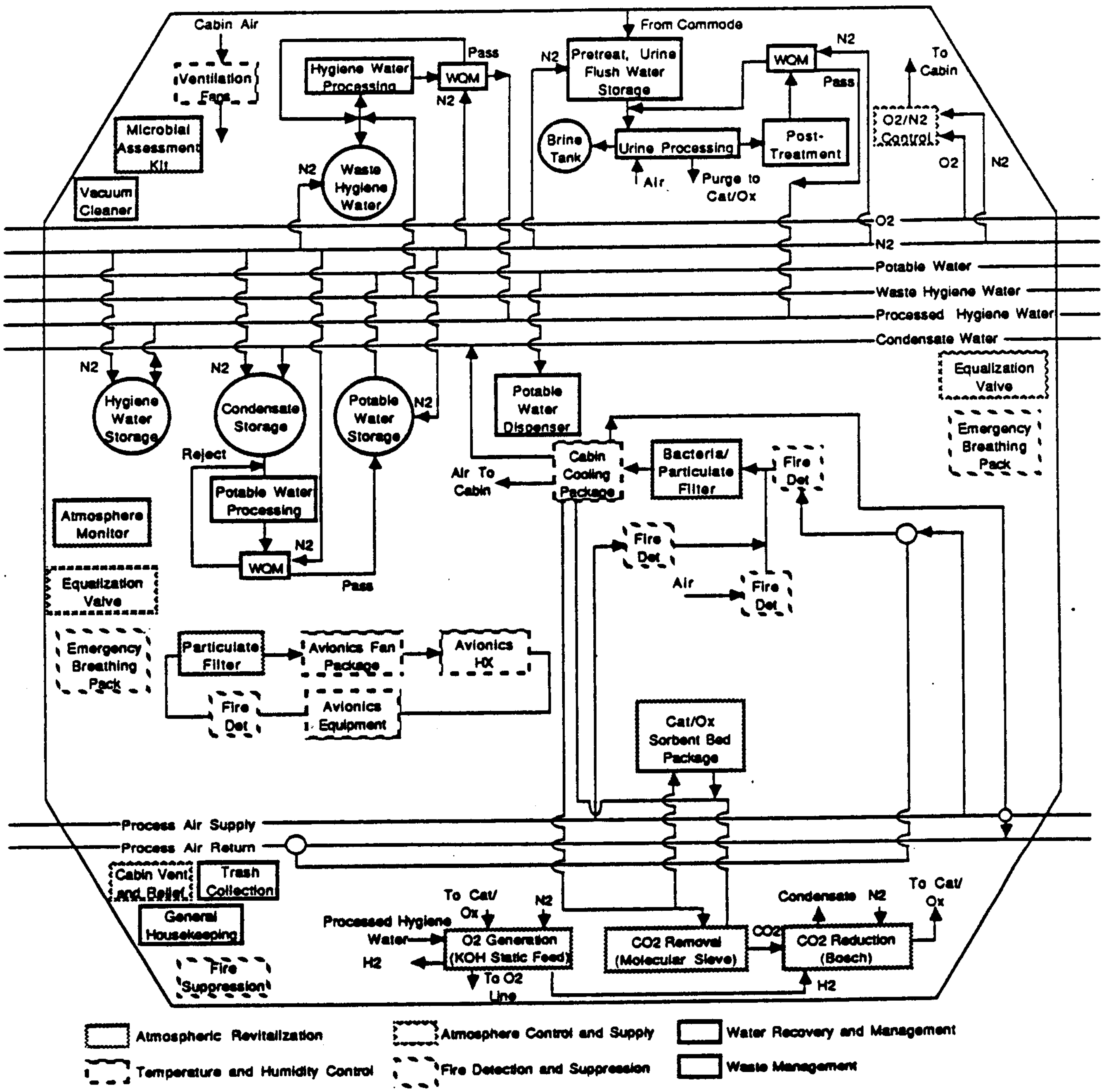

Figure 3.1-1 System Schematic for the Environmental Control and Life Support System

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Table 3.1-3 Component List for the Environmental Control and Life Support System

ITEM	PROGRAM APPLICATON	COMPONENT TYPE	QUAN REQD	SIZE (in)	PRESSURE MEOP (psia)	USAGE MEDIA	APPROX MASS (lb)	VENDOR NAME	VENDOR PART NUMBER
115	ECLSS, ACS	MISC, CONTROL, N2 RESUPPLY PRESSURE	1	TBD	TBD	GN2	57.0	TBD	TBD
89	ECLSS, ACS	MISC, PRESSURE CONTROL SYSTEM	5	.375	250	GO2, GN2	50.0	TBD	TBD
113	ECLSS, ACS	MISC, REFRIGERATOR/FREEZER	3	TBD	TBD	TBD	546.0	TBD	TBD
114	ECLSS, ACS	PRESSURE VESSEL,	2	TBD	TBD	LN2	170.0	TBD	TBD
87	ECLSS, ACS	REGULATOR, DOWNSTREAM	2	.375	4000	GN2	5.0	TBD	TBD
90	ECLSS, ACS	VALVE, EQUALIZATION	9	TBD	14.9	AIR	6.0	TBD	TBD
88	ECLSS, ACS	VALVE, RELIEF	5	TBD	14.9	AIR	3.0	TBD	TBD
92	ECLSS, AR	FILTER, AVIONICS PARTICULATE	4	TBD	14.9	AIR	17.0	TBD	TBD
95	ECLSS, AR	FILTER, BACTERIA/PARTICULATE	7	TBD	14.9	AIR	60.0	TBD	TBD
99	ECLSS, AR	MISC, CATALYTIC OXIDIZER	4	TBD	30	AIR	80.0	TBD	TBD
94	ECLSS, AR	MISC, CO2 REDUCTION, BOSCH	4	.25	30	AIR	320.0	TBD	TBD
97	ECLSS, AR	MISC, ELECTROLYSIS UNIT, KOH	4	TBD	200	H2O, CO2, GH2	232.0	TBD	TBD
96	ECLSS, AR	MISC, MOLECULAR SIEVE, 4-BED	4	TBD	30	AIR, CO2	322.0	TBD	TBD
98	ECLSS, AR	MISC, MONITOR, ATMOSPHERE	5	TBD	14.9	AIR	57.0	TBD	TBD
93	ECLSS, AR	MISC, SORBENT BED	4	TBD	30	AIR	90.0	TBD	TBD
101	ECLSS, FDS	MISC, CONTROLLER, PYRO	7	N/A	500	HALON 1301	2.0	TBD	TBD
100	ECLSS, FDS	PRESSURE VESSEL, FIRE SUPPRESSANT	76	TBD	500	HALON 1301	8.0	TBD	TBD
91	ECLSS, THC	MISC, CABIN COOLING PKG	7	TBD	14.9	AIR	123.0	TBD	TBD
116	ECLSS, WM	MISC, BRINE STORAGE	6	TBD	TBD	URINE BRINE	33.0	TBD	TBD
117	ECLSS, WM	MISC, FECAL STORAGE	1	TBD	TBD	FECES	52.0	TBD	TBD
103	ECLSS, WRM	MISC, DISPENSER, POTABLE WATER	2	TBD	44.9	H2O	41.0	TBD	TBD
109	ECLSS, WRM	MISC, EYEWASH	1	TBD	44.9	H2O	1.0	TBD	TBD
106	ECLSS, WRM	MISC, MONITOR, WATER QUALITY	8	TBD	44.9	H2O	68.0	TBD	TBD
108	ECLSS, WRM	MISC, PROCESSING UNIT, POTABLE WATER	4	TBD	44.9	H2O	77.0	TBD	TBD
107	ECLSS, WRM	MISC, PROCESSING UNIT, WASTE HYGIENE	2	TBD	44.9	H2O	202.0	TBD	TBD
105	ECLSS, WRM	PRESSURE VESSEL, CONDENSATE WATER	2	TBD	44.9	H2O	108.0	TBD	TBD
104	ECLSS, WRM	PRESSURE VESSEL, EMERGENCY WASH WATER	2	TBD	44.9	H2O	128.0	TBD	TBD
112	ECLSS, WRM	PRESSURE VESSEL, HYGIENE WATER	1	TBD	44.9	H2O	1000.0	TBD	TBD
102	ECLSS, WRM	PRESSURE VESSEL, POTABLE WATER	4	TBD	44.9	H2O	166.0	TBD	TBD
110	ECLSS, WRM	PRESSURE VESSEL, PROCESSED HYGIENE WATER	2	TBD	44.9	H2O	315.0	TBD	TBD
111	ECLSS, WRM	PRESSURE VESSEL, WASTE HYGIENE WATER	2	TBD	44.9	H2O	292.5	TBD	TBD

Table 3.1-4 Fluid Storage and Resupply Quantity Requirements Categorized by Fluid Media

ID NO.	FLUID TYPE	FLUID SYSTEM	FLUID SUBSYSTEM	QUANTITY STORED	USAGE RATE (LB/HR)	RESUPPLY QUANTITY (LB/90 DAYS) MEAN	RESUPPLY QUANTITY (LB/90 DAYS) MAX	RESUPPLY METHOD	FLUID COMPOSITION	REMARKS
13	ACETYLENE	USL	PFS	TBD	TBD	0.0	0.0	PPV	TBD	
49	AIR	JEM	EXPERIMENT FLUIDS	TBD	TBD	17.6	TBD	ELM	DRY AIR	USED FOR REACTIONS IN MATERIALS PROCESSING EXPERIMENTS. STABLE GAS
39	AIR	JEM	HOUSEKEEPING	TBD	100-220 CU M/HR	TBD	TBD	RECYCLED BY ECLSS	TBD	AIR IS USED FOR VENTILATION AND BREATHING.
45	AIR	JEM	HOUSEKEEPING WASTE	TBD	100-220 CU M/HR	TBD	TBD	CABIN VENTILATION	TBD	CABIN AIR IS DUCTED BACK TO SS ECLSS FOR PROCESSING.
46	AIR	JEM	HOUSEKEEPING WASTE	TBD	TBD	115	TBD	SS ECLSS	TBD	AIR IS FOR RESUPPLY OF THAT LOST TO SPACE BY LEAKAGE, AIR LOCK AND DOCKING PORT USE ONLY.
11	AIR	USL	PFS	0.0	TBD	89.3	97.7	FLUID TRANSFER FROM ECLSS	SEE REMARKS	PPO2=2.83 TO 3.35 PSIA PPN2=11.87 TO 11.35 PSIA
47	AIR/GN2	JEM	HOUSEKEEPING WASTE	TBD	TBD	.22	TBD	SS ECLSS	TBD	USED ONLY FOR MAKEUP OF TCS MAINTENANCE AND COOLANT RESUPPLY GASES LOST TO SPACE
24	ALCOHOL	USL	PFS	TBD	TBD	TBD	TBD	PPV	TBD	
56	AMMONIA	JEM	EXPERIMENT FLUIDS	TBD	TBD	1.1	TBD	ELM TANK CHANGEOUT	TBD	USED AS REACTANT FOR MATERIALS PROCESSING. TOXIC. CORROSIVE.
57	Ar	IMFS	ATT. PAYLOADS	80.5	TBD	TBD	TBD	FLUID TRANSFER FROM ATT. P/L	TBD	PRESENTLY NO REQUIREMENT TO INTEGRATE ATTACHED PAYLOADS FLUIDS WITH SPACE STATION.
114	Ar	IMFS	COL	TBD	TBD	41.75	41.75	FLUID TRANSFER FROM COLUMBUS	TBD	
105	Ar	IMFS	JEM	TBD	TBD	152	152	FLUID TRANSFER FROM JEM	TBD	
96	Ar	IMFS	USL	TBD	TBD	41.75	83.5	FLUID TRANSFER FROM USL	TBD	
50	Ar	JEM	EXPERIMENT FLUIDS	TBD	TBD	151.8	TBD	ELM	TBD	USED FOR MATERIALS PROCESSING EXPERIMENT ATMOSPHERE PREPARATION. STABLE GAS. INERT
7	Ar	USL	PFS	55.5	TBD	32.6	37.0	FLUID TRANSFER/PPV	TBD	
71	BRINE	ECLSS	HM	476	0.220 NOM			TAKE TO EARTH	38% SOLIDS	STORED FOR TRANSPORT TO EARTH
19	BUFFER SOLUTION	USL	PFS	TBD	TBD	TBD	TBD	PPV	TBD	
21	BUTANE	USL	PFS	TBD	TBD	TBD	TBD	PPV	TBD	
75	CARBON, SOLID	ECLSS	WRM		0.203			FROM BOSCH		USING BOSCH CO2 REDUCTION
14	CLEANING SOL'N	USL	PFS	248.4	TBD	117.1	165.6	PPV	TBD	
59	C12	JEM	EXPERIMENT FLUIDS	TBD	TBD	4.4	TBD	ELM TANK CHANGEOUT	TBD	USE AS REACTANT IN MATERIALS PROCESSING. CORROSIVE. TOXIC. EXPLOSIVE WITH PROPANE.

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Table 3.1-5 Fluid Interface Data Categorized by Fluid Media

ID NO.	FLUID TYPE	FLUID SYSTEM	FLUID SUBSYSTEM	INLET AND OUTLET FLUID CONDITIONS: FROM TO	PRESSURE (PSIA)	TEMP. (F)	LINE SIZES (INCHES)	METHOD OF WASTE MANAGEMENT	FAILURE TOLERANCE	REMARKS
13	ACETYLENE	USL	PFS	LOG MOD EXPERIMENT	TBD TBD	70 70	PPV PPV	PMMS	ZERO	FAILSAFE
49	AIR	JEM	EXPERIMENT FLUIDS	ELM EXPERIMENTS	19 TBD	TBD TBD	TBD TBD	VENT TO SPACE	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.
39	AIR	JEM	HOUSEKEEPING	SS ECLSS CABIN VENTILATION	TBD TBD	TBD TBD	TBD TBD	RETURN TO ECLSS THRU PLUMBING	TBD	AIR IS REVITALIZED BY SS CORE ECLSS (SCRUBBING, CO2 REDUCTION) AND RECYCLED.
45	AIR	JEM	HOUSEKEEPING WAST	CABIN VENTILATION SS ECLSS	TBD TBD	TBD TBD	TBD TBD	RETURN TO SS CORE ECLSS	TBD	AIR IS REVITALIZED BY SS CORE ECLSS
46	AIR	JEM	HOUSEKEEPING WAST	CABIN VENTILATION SPACE	TBD TBD	TBD TBD	TBD TBD	LEAKAGE AND VENT TO SPACE	TBD	AIR MUST BE MADE UP WHEN LOST TO SPACE
11	AIR	USL	PFS	ECLSS EXPERIMENT	14.7 70	70 14.7	.25 .25	PMMS	ZERO	FAILSAFE
47	AIR/GN2	JEM	HOUSEKEEPING WAST	SS ECLSS SPACE	TBD TBD	TBD TBD	TBD TBD	VENT TO SPACE	TBD	AIR/N2 USED FOR MAINTENANCE AND COOLANT MAKEUP IN TCS
24	ALCOHOL	USL	PFS	LOG MOD EXPERIMENT	TBD TBD	70 70	PPV PPV	PMMS	ZERO	FAILSAFE
56	AMMONIA	JEM	EXPERIMENT FLUIDS	ELM INDIVIDUAL TANK EXPERIMENT	<19 TBD	TBD TBD	TBD TBD	VENT TO SPACE AFTER TREATING	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.
50	Ar	JEM	EXPERIMENT FLUIDS	ELM COMMON GAS SUPP. EXPERIMENT ATMOSPHER	19 TBD	TBD TBD	TBD TBD	VENT TO SPACE	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.
7	Ar	USL	PFS	LOG MOD EXPERIMENTS	3000/2000 50	70 70	.25/PPV .25	PMMS	ZERO	FAILSAFE
71	BRINE	ECLSS	WM	TIMES PLC				STORE IN TANKS TO TRANSPORT		
19	BUFFER SOLUTION	USL	PFS	LOG MOD EXPERIMENT	TBD TBD	70 70	PPV PPV	PMMS	ZERO	FAILSAFE
21	BUTANE	USL	PFS	LOG MOD EXPERIMENT	TBD TBD	70 70	PPV PPV	PMMS	ZERO	FAILSAFE
75	CARBON, SOLID	ECLSS	WRM	BOSCH PLC		980-1340 AMBIENT		STORE IN PLC		BOSCH
14	CLEANING SOL'N	USL	PFS	LOG MOD EXPERIMENT	TBD TBD	70 70	PPV PPV	PMMS	ZERO	FAILSAFE
59	C12	JEM	EXPERIMENT FLUIDS	ELM INDIVIDUAL TANK EXPERIMENT	<19 TBD	TBD TBD	TBD TBD	VENT TO SPACE AFTER PROCSSING	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.
44	CO2	JEM	HOUSEKEEPING WAST	RESPIRATION SS ECLSS	TBD TBD	TBD TBD	TBD TBD	PIPED TO SS ECLSS	TBD	JEM ECLSS REMOVES CO2 FROM ATMOSPHERE. REDUCTION OCCURS IN SS ECLSS.
67	CO2	JEM	LIFE SCIENCE FLUI	ELM COMMON SUPPLY LIFE EXPERIMENT	14.7 TBD	TBD TBD	TBD TBD	VENT TO SPACE	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.
63	CO2	JEM	SUBPRODUCT FLUIDS	EXPERIMENT DISPOSAL	TBD TBD	TBD TBD	TBD TBD	VENT TO SPACE AFTER TREATING	TBD	VENT TO SPACE MAY NOT BE ALLOWED. WASTE WOULD BE COLLECTED AND SENT TO INTEGRATED WASTE SYSTEM.

components that had been specified for particular applications or components with capabilities that closely match the requirements of those applications. Hardware data were also categorized into existing hardware, hardware that requires development work, and new hardware that requires technology development. Examples of the component data included in EP 2.3, the "Space Station Program Fluid Systems Hardware Catalog," are presented in Tables 3.2-1 and 3.2-2.

3.3 FLUID SYSTEM COMMONALITY ASSESSMENT

Two separate assessments of fluid system commonality were performed over the duration of this study. The first was performed under Task I and was incorporated into EP 2.3, the "Space Station Program Fluid Systems Hardware Catalog." This original assessment examined hardware commonality among propulsion systems by comparing hardware which had been defined in Space Station Program documentation and had been included in the Space Station fluid system component database. Components which were indicated for use in more than one propulsion system were listed as common hardware. Initial efforts on the Integrated Fluid System Definition indicated a need for a more extensive commonality study. The realization that many fluid systems had not been defined to the component level provided an opportunity to design toward a goal of maximum commonality. This reexamination of fluid system hardware commonality as a design driver instead of just a result has been completed and is presented later in this section. In addition to hardware commonality among fluid systems, there is also a need to identify those systems which share common requirements. The following analysis was performed prior to system definition to determine where system integration was appropriate.

3.3.1 Fluid System Requirements Commonality

Commonality of requirements for fluid systems was examined using two preliminary selection criteria. Fluids which were shown to have more than one user were identified as integration candidates, as were by-product fluids which have potential either for recycling for further use within the Space Station as a non-waste fluid or for use in the integrated waste fluids system. The fluids chosen as possibly benefitting from integration as fluid systems, based on the preliminary selection criteria, are presented in Table 3.3-1. Table 3.3-2 shows by-product fluids that have potential for use in the integrated waste fluids system.

3.3.2 Fluid Systems Hardware Commonality

The issue of hardware commonality among fluid systems affects both the design of the fluid systems and the cost of building them. Designing several hardware systems to incorporate a great deal of hardware commonality may prevent each system from being built with its *individual* optimum design. An analysis must be performed to determine the best possible mix of design optimization and commonality optimization, which is the *common* optimum design for the several systems. This design should provide the lowest cost system which meets all the requirements of the systems. The following example shows the relationship between the individual optimum design and the common optimum design.

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Table 3.2-1 Component Listing by Fluid Media Type

USAGE (MEDIA)	SHEET NUMBER	ITEM NO.	PROGRAM APPLICATION	COMPONENT TYPE	SUB-TYPE	PRESSURE MEOP (psia)	PORT SIZE (in)	APPROX. MASS (lb)	QUANTITY REQUIRED	VENDOR	VENDOR PART NUMBER
H2O	1	199	IMFS, IMS	DISCONNECT		30	.25	0.8	16	SYMETRICS INC.	502040-1011 & -3012
H2O	1	30	USL, PFS	DISCONNECT		100	.25	0.8	44	SYMETRICS INC.	502040-1011 & -3012
H2O	3	33	USL, PFS	DISCONNECT		100	.375	0.4	36	SYMETRICS INC.	592002-3 & -4
H2O	7	217	IMS,	DISCONNECT		30	TBD	TBD	4	TBD	TBD
H2O	13	14	USL, PFS	FILTER	INLINE	100	.375	5.5	1	TBD	TBD
H2O	15	215	IMS,	FILTER	INLINE	30	TBD	1.0	TBD	TBD	TBD
H2O	10	73	USL, PMM	FILTER	MULTIPLE	100	.375	40.5	1	TBD	TBD
H2O	31	103	ECLSS, WMM	MISC	DISPENSER, POTABLE WATER	44.9	TBD	41.0	2	TBD	TBD
H2O	33	109	ECLSS, WMM	MISC	EYEWASH	44.8	TBD	1.0	1	TBD	TBD
H2O	36	7	USL, PFS	MISC	FLEX HOSE	50	.375	0.4	1	TBD	TBD
H2O	37	12	USL, PFS	MISC	FLEX HOSE	100	.375	1.1	1	TBD	TBD
H2O	45	216	IMS,	MISC	HEATER	N/A	N/A	0.5	305	TBD	TBD
H2O	48	106	ECLSS, WMM	MISC	MONITOR, WATER QUALITY	44.9	TBD	60.0	8	TBD	TBD
H2O	53	108	ECLSS, WMM	MISC	PROCESSING UNIT, POTABLE	44.9	TBD	77.0	4	TBD	TBD
H2O	54	107	ECLSS, WMM	MISC	PROCESSING UNIT, WASTE HY	44.9	TBD	202.0	2	TBD	TBD
H2O	55	23	USL, PFS	MISC	PUMP	100	.375	11.4	1	TBD	TBD
H2O	57	200	IMFS,	MISC	PUMP	TBD	TBD	35.0	2	TBD	TBD
H2O	65	61	USL, PMM	MISC	TIMES UNIT	100	.375	95.0	1	HAMILTON STANDARD	TBD
H2O	71	16	USL, PFS	MISC	WATER PROCESSOR	100	.375	66.2	1	TBD	TBD
H2O	72	203	IMFS,	PRESSURE VESSEL		30	.25	42.0	1	TBD	TBD
H2O	76	19	USL, PFS	PRESSURE VESSEL		100	.375	33.1	1	TBD	TBD
H2O	80	210	IMS,	PRESSURE VESSEL		30	TBD	76.0	8	TBD	TBD
H2O	84	205	IMFS,	PRESSURE VESSEL	ACCUMULATORS	TBD	.25	3.2	1	TBD	TBD
H2O	86	105	ECLSS, WMM	PRESSURE VESSEL	CONDENSATE WATER	44.9	TBD	108.0	2	TBD	TBD
H2O	87	104	ECLSS, WMM	PRESSURE VESSEL	EMERGENCY WASH WATER	44.9	TBD	120.0	2	TBD	TBD
H2O	89	112	ECLSS, WMM	PRESSURE VESSEL	HYGIENE WATER	44.9	TBD	800.0	1	TBD	TBD
H2O	94	102	ECLSS, WMM	PRESSURE VESSEL	POTABLE WATER	44.9	TBD	166.0	4	TBD	TBD
H2O	95	15	USL, PFS	PRESSURE VESSEL	PROCESS WATER	100	.375	880.3	1	TBD	TBD
H2O	96	110	ECLSS, WMM	PRESSURE VESSEL	PROCESSED HYGIENE WATER	44.9	TBD	315.0	2	TBD	TBD
H2O	98	21	USL, PFS	PRESSURE VESSEL	STORAGE CONT.	50	.375	15.4	1	TBD	TBD
H2O	102	111	ECLSS, WMM	PRESSURE VESSEL	WASTE HYGIENE WATER	44.9	TBD	292.5	2	TBD	TBD
H2O	109	13	USL, PFS	SENSOR	FLOW METER	100	.375	2.0	2	TBD	TBD
H2O	117	213	IMS,	SENSOR	PRESSURE	30	.25	0.5	20	MOOG, CARLETON GROUP	2731-0001-5
H2O	117	193	IMFS,	SENSOR	PRESSURE	30	.25	0.5	14	MOOG, CARLETON GROUP	2731-0001-5
H2O	123	22	USL, PFS	SENSOR	DELTA PRESSURE	100	.375	0.5	1	TBD	TBD
H2O	124	25	USL, PFS	SENSOR	QUALITY METER	100	.375	2.2	1	TBD	TBD

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Table 3.2-2 Technology Development Hardware Data

HARDWARE SHEET NO.	COMPONENT TYPE	SUB-TYPE	PROGRAM APPLICATION	STATE OF DEVEL.	GENERAL COMMENTS
5	Disconnect		SFHT	3	Moog Space Products has a development design which has been tested as a prototype.
9	Disconnect	Emergency	SFHT	1	Currently only at preliminary definition stage.
23	Miscellaneous	CO2 Reduction, Bosch	ECLSS, AR	5	Prototype unit has only been laboratory tested.
24	Miscellaneous	Compressor	IWFS	1	No design currently available to compress hydrogen and meet high life limits.
25	Miscellaneous	Compressor	IWFS	3	OLOGS compressor modified to meet the life reqt needs to be tested.
32	Miscellaneous	Electrolysis Unit	ECLSS, AR	5	Prototype unit has only been laboratory tested.
46	Miscellaneous	Molecular Sieve, 4 Bed	ECLSS, AR	5	Prototype unit has only been laboratory tested.
49	Miscellaneous	Porous Plug	SFHT	1	Has never been demonstrated for this application.
50	Miscellaneous	Porous Plug	SFHT	1	Has never been demonstrated for this application.
58	Miscellaneous	Pump, FEP	SFHT	1	Has never been demonstrated for this application.
65	Miscellaneous	TIMES Unit	USL, PWH	5	Prototype unit has only been laboratory tested.
90	Miscellaneous	Pressure Vessel, Isogrid	SFHT	1	Has never been demonstrated for this application.
97	Miscellaneous	Pressure Vessel, Stiffened Monocoque	SFHT	4	Has never been demonstrated for this application.

State of Devel. Value	State of Development Value Definitions
1	Basic Principles Observed and Reported
2	Conceptual Design Formulated
3	Conceptual Design Tested
4	Critical Hardware Tested
5	Preprototype Tested
6	Prototype Tested
7	Engineering Model Tested
8	Operational

Table 3.3-1 Candidates for Development as Integrated Fluid Systems

Air	Hydrogen
Argon	Nitrogen
Carbon dioxide	Oxygen
Cleaning Solution	Waste Fluids
Freon	Water
Helium	

Table 3.3-2 Candidates for Disposal to the Integrated Waste Fluids System

Acetylene	Gaseous Helium
Air	Gaseous Nitrogen
Alcohol	Gaseous Oxygen
Argon	Methane
Buffer Solution	Nutrients
Carbon Dioxide	Propane
Cleaning Solution	Solvents
Carbon dioxide/Methane	Stains
Culture Media	Sterilizers
Cutting Polish	Water
Fuels	Xenon
Gaseous Hydrogen	Xylene

The optimum design of an argon gas delivery system is shown in Figure 3.3-1, and includes two 1 ft^3 storage tanks, each pressurized to 3000 psia. Figure 3.3-2 also shows a gas delivery system, this one for krypton gas. The optimum krypton system requires one 1 ft^3 storage tank pressurized to 2000 psia. Both of these tanks must be independently designed, developed and tested, incurring a great deal of initial cost for each. A less expensive solution uses only one tank design, building three of the 1 ft^3, 3000 psia tanks, or four of the 1 ft^3, 2000 psia tanks to meet the needs of both storage systems. This combination replaces two individual optimum designs with one common optimum design.

Five levels of component commonality have been identified:

1) No Hardware Commonality, where an individual system shares no hardware with other systems;
2) Partial Component Commonality, where some components are also used in other fluid systems, but not in identical sub assemblies;
3) Total Component Commonality, where all components are also used in other fluid subsystems, but not as identical subassemblies;
4) Partial System Commonality, where identical subassemblies are used in other systems; and,
5) Total System Commonality, where identical hardware systems are installed for other fluids also.

Examples of groups of systems which demonstrate these five levels of commonality are shown in Figure 3.3-3. When these five levels of hardware commonality are applied to multiple fluid systems, it quickly becomes apparent that there are several combinations of the five levels. The following example expands on the one presented previously.

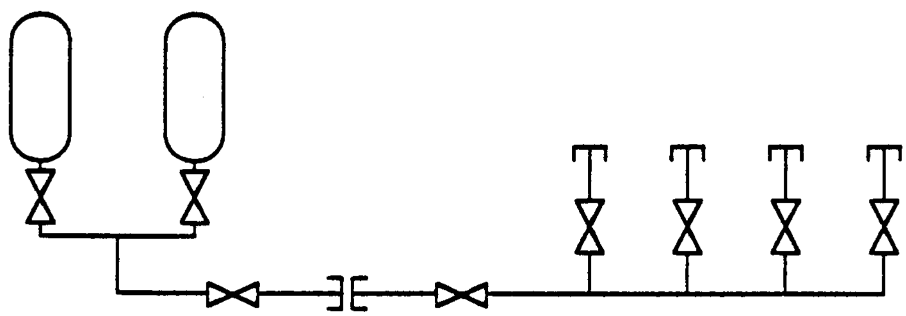

Figure 3.3-1 Example of an Argon Gas Delivery System

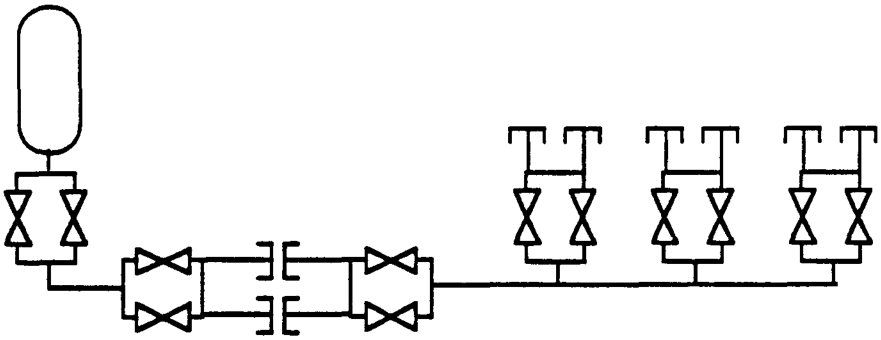

Figure 3.3-2 Example of a Krypton Gas Delivery System

A xenon delivery system is required along with the argon and krypton systems identified previously and is being considered as a commonality candidate. The storage and delivery requirements are essentially the same as those for the krypton system, which will allow the use of the identical design for both systems. Ranking these three systems together with the scale listed above gives the following results.

Xenon ranks:
- 5 with krypton
- 2 with argon

Krypton ranks:
- 5 with xenon
- 2 with argon

Argon ranks:
- 2 with xenon
- 2 with krypton

Further analysis shows that there are many possible combinations when a large number of systems are mutually ranked. The total number of possible combinations is sixteen, ranked 0 to 15, which are shown below:

15)	5
14)	5,4
13)	5,4,3
12)	5,4,3,2
11)	5,4,2
10)	5,3
9)	5,3,2
8)	5,2
7)	4
6)	4,3
5)	4,3,2
4)	4,2
3)	3
2)	3,2
1)	2
0)	1

Although this list is more complete and includes all the possible levels of commonality, it is quite confusing and does not directly point out those systems into which a high level of commonality has been designed. A third list of commonality rankings was generated which includes combinations of levels where they are appropriate, but also limits the analysis to the highest commonality level which a given system might have with any of the other systems.

There are seven levels of commonality in this system, ranked 0 to 6, which are listed below:

6) 5 Identical duplicate systems are used with at least one other fluid.
5) 4 All subasemblies are used with at least one other fluid.
4) 4,3 Some subassemblies are used with at least one other fluid, and the remaining components are also used with at least one other fluid.
3) 4,2 Some subassemblies are used with at least one other fluid, and some of the remaining components are also used with at least one other fluid.
2) 3 All the individual components are also used in other fluid systems, but not as identical subassemblies.
1) 2 Some of the individual components are also used in other fluid systems, but not as identical subassemblies.
0) 1 No hardware commonality.

Each gas listed in Table 3.3-3 was analyzed to determine the level of commonality it shares with each of the others to determine its maximum commonality ranking. Included in Table 3.3-3 are the commonality ranking assigned to each gas, and the gas(es) with which the ranked gas achieved that ranking. Table 3.3-4 shows the same information for the liquids in the study.

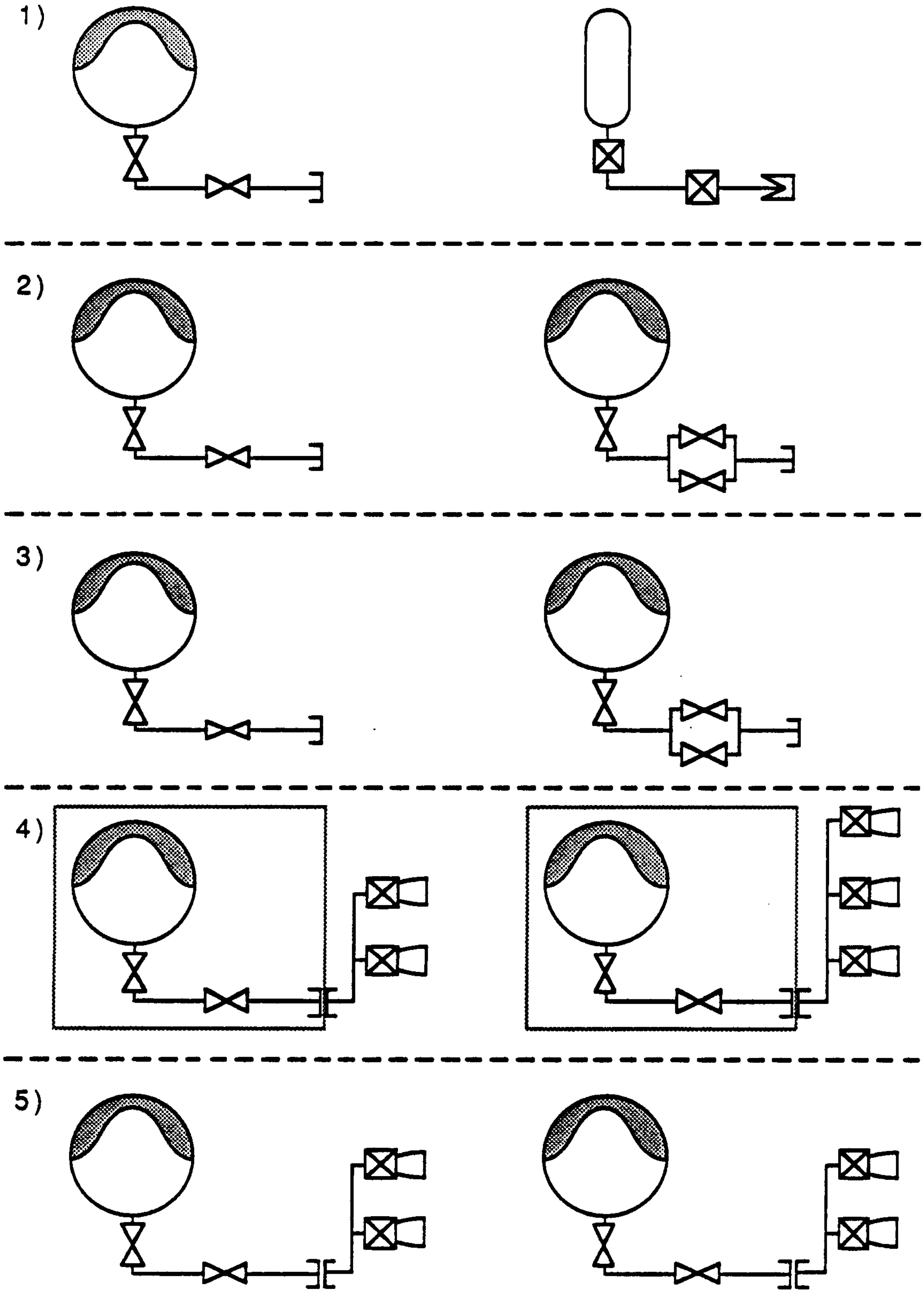

Figure 3.3-3 The Five Primary Commonality Levels

Table 3.3-3 Commonality Among Gases in the USL, COL and JEM Laboratories and Attached Payloads

Gas	Quantity	Volume*	Ranking	Common Systems
Ar	236.0	7.6	6	H_2, NH_3
Cl_2	8.8	6.6	5	Ar, NH_3,H_2
CO_2	63.0	7.9	5	Ar, Kr
CO_2/CH_4	958.0	-	2	CO_2
C_2H_2 (Acetylene)**	-	-	0	N/A
C_3H_8 (Propane)	6.6	0.9	6	Xe, Kr, SiH_4
C_4H_{10} (Butane)	-	-	-	-
H_2	1.3	3.8	6	Ar, NH_3
He	8.5	12.4	6	N_2
Kr	9.9	0.6	6	Xe, C_3H_8, SiH_4
N_2	188.0	37.8	6	He
NH_3 (Ammonia)	2.2	5.5	6	Ar, H_2
O_2	87.0	14.9	5	N_2, He
SiH_4 (Silane)	6.6	0.6	6	Kr, Xe, C_3H_8
Xe	33.0	0.4	6	Kr, C_3H_8,SiH_4

* Volumes are at 1000 psia and 70°F except Cl_2 @ 95 psia, Ammonia @ 120°F, Butane @ 30 psia and Propane @ 120 psia to avoid liquefaction.

** Acetylene must be stored in special tanks. No commonality is possible.

Table 3.3-4 Commonality Among Liquids

Liquid	Quantity	Ranking	Common Systems
Alcohol	TBD	2	Cleaning Solution
Cleaning Solution	TBD	2	Alcohol
Freon	TBD	TBD	
HCl	TBD	2	Toluene, Xylene
He	TBD	1	N_2
N_2	TBD	1	He
Toluene	TBD	2	HCl, Xylene
Water	TBD	0	N/A
Xylene	TBD	2	HCl, Toluene
Other *	TBD	3	

* Other includes buffer solution, culture media, cutting polish, echants, nutrients, solvents, stains, and sterilizers.

3.4 INTEGRATED EXPERIMENT GAS SUPPLY AND DISTRIBUTION SYSTEMS

The fluid systems for which integration was investigated included several experiment gases. The supply and distribution systems of argon, carbon dioxide, helium, and experiment air were examined to determine the possible benefits of uniting the many individual gas supplies necessary into four systems, one for each gas. In addition, the possible use of similar designs for each of these systems was studied.

3.4.1 Experiment Gas Usage

Argon is used in the USL, JEM, and Columbus laboratories on the Space Station, and in the Solar Terrestrial Observatory attached payload. Because of the large quantities of argon required, about 316 lbm per 90 days, the argon supply system looks to be a good candidate for integration. Of this 316 lbm, 80 lbm is used by the attached payload. The remaining 236 lbm is divided among the three laboratories.

Carbon dioxide is used in the USL, JEM, and Columbus laboratories on the Space Station. Because of the quantities of carbon dioxide required, about 63 lbm per 90 days, the carbon dioxide supply system also looks to be a good candidate for integration. Also of note is the fact that the Environmental Control and Life Support System (ECLSS) produces carbon dioxide as a by-product of its air revitalization process.

Helium is used in the USL, JEM, and Columbus laboratories on the Space Station and in the Active Optic Technology attached payload. The use of helium by the Space Station experimental modules is very minimal, about 8.5 lbm per 90 days which occupies a storage volume of 1 cubic foot or less at the proposed storage pressures of 2000 to 3000 psia. The 8.5 lbm is comprised of 4.4 lbm for the USL Module, 1.9 lbm for the JEM Module and 2.2 lbm for the Columbus Module. At least one of the attached payload experiments uses a large amount of helium, 180.4 lbm, which is supplied in a superfluid helium dewar. A portion of the gaseous helium effluent from the attached payloads may be used in the experimental modules. The small quantities of helium required limit the practicality of integrating helium supply and distribution systems into one integrated system.

Air is used for two functions on the Space Station: cabin air and experiment air. Cabin air makes up the breathable living environment for the crew. This air contains water, carbon dioxide and other contaminants besides the primary constituents, oxygen and nitrogen. Cabin air will vary in composition depending on crew size, airlock usage, and cabin leakage. The partial pressure of oxygen and the total cabin pressure are monitored and maintained by adding oxygen and nitrogen individually as required. Carbon dioxide and other contaminants are removed from the cabin air by the Space Station's Environmental Control and Life Support System.

Dry, contaminant-free air is required by experiments in all three laboratories. This air is used for respiration, purging, and as a reagent. Total and partial pressure requirements of the air and its constituents are not available for these experiments. If there is any variation in the properties of the air required, the air must be made up from its constituents, oxygen and nitrogen, in the proper mixture to meet the requirements. This mixing is performed by the individual experiments. This mixing requirement, along with the fact that both nitrogen and oxygen are already supplied throughout the Space Station modules, eliminates the need for an integrated air system.

In the case that air need be supplied as a common gas, the supply and distribution systems would be similar to those of the experiment gas supply system. Refer to the integrated experiment gas supply system definition for a discussion of the apparatus.

3.4.2 Integrated Experiment Gas Supply Systems

The following are descriptions of possible experiment gas system configurations. Two different parts of the overall systems are discussed. The supply system configurations provide the means for bringing the gases to the Space Station on the NSTS Shuttle and supplying them to common locations. The distribution systems take the gases from the supply systems and distribute them to the locations where they are required, such as in an experiment rack. The optimum experiment gas system for each gas will be derived by combining one of the supply systems with one of the distribution systems, and may include the benefits realized from the use of similar systems for more than one gas. The selection of the most appropriate overall system for Space Station will be made after considering cost impacts and other factors such as operational flexibility, safety, reliability, and maintenance.

3.4.2.1 Baseline Supply and Distribution Configurations - Space Station Program documents call out only one means for the supply of experiment gases to their various users, a process fluids rack with numerous pressure vessels for the supply of the required process gases. The gases are delivered to their users by manually removing the pressure vessels from the fluids rack and installing them in the experiment racks. Figure 3.4-1 shows a design concept for the fluids rack. No further description of this system is provided. Figure 3.4-2 shows a Space Station module layout and how the fluids rack is located in it. The use of portable pressure vessels provides a great deal of flexibility; however, it also makes transportation (launch) costs high by decreasing the usable mass fraction. Resupply using a fluids rack eliminates the need to return unused gases to Earth on board the Logistics Module when they are not used on schedule.

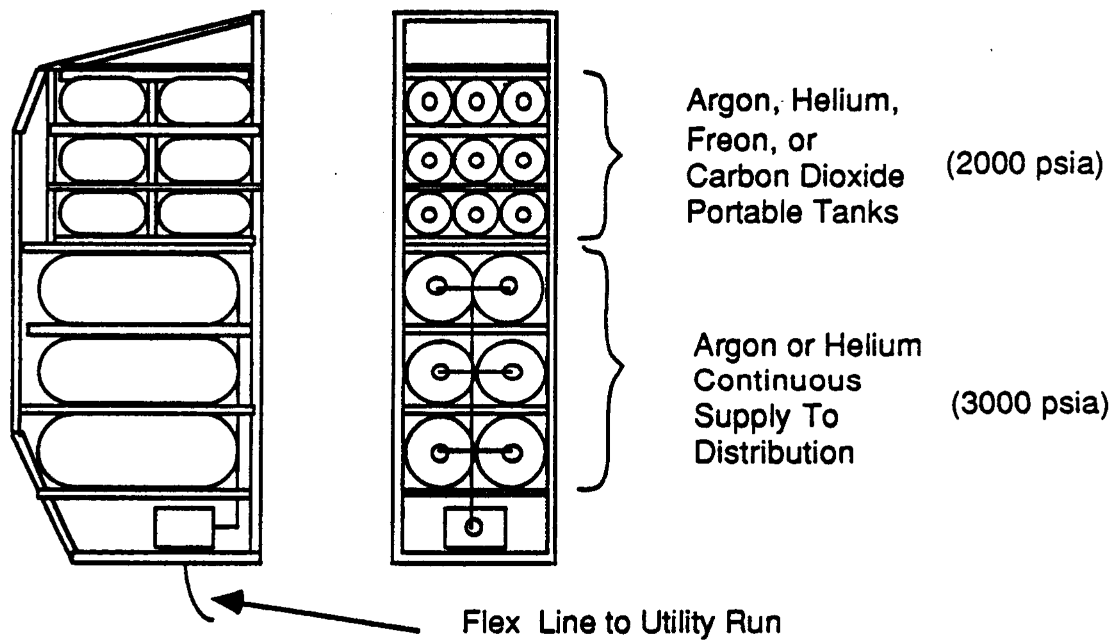

Figure 3.4-1 Fluids Rack Design Concept

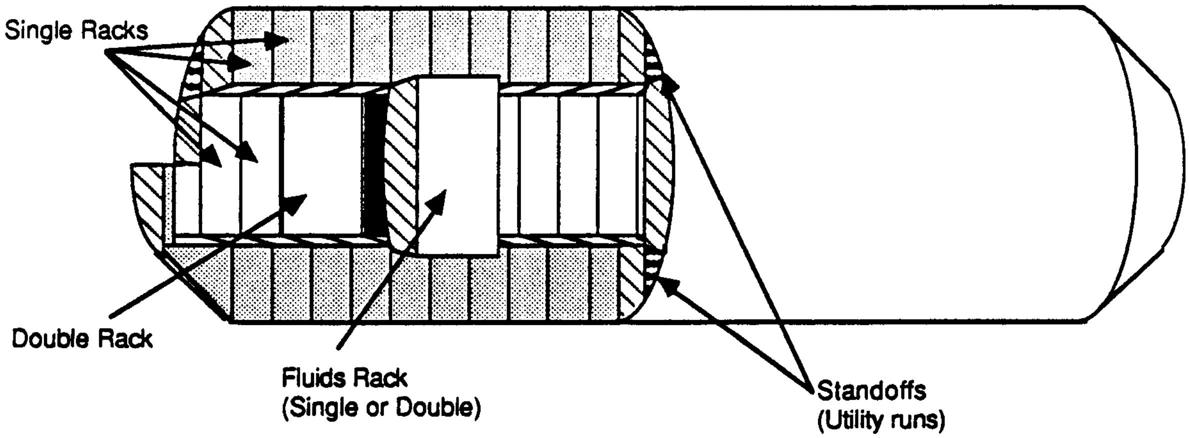

Figure 3.4-2 Location of Fluids Rack in Space Station Module

3.4.2.2 Supply Configurations for Integrated Systems - There are several methods of supplying the experiment gases in addition to the baseline method discussed previously. Carbon dioxide, helium, and argon can all be brought to the Space Station as liquids or gases, and carbon dioxide can also be transported as a solid. The liquid and solid forms of these chemicals have higher densities than the gas forms, but they present storage and distribution problems that make them more difficult to deliver to their users.

Gases can be supplied to the Space Station at moderate pressures (1000-3000 psia) at ambient temperature (70°F). As explained previously, the baseline gas systems supply the gases to their users in small individual pressure tanks, some of which are used for batch resupply. These gases are better supplied, however, by delivering one or two large pressure tanks of each gas to the Space Station, and subsequently distributing the gases to their users. Fluid conditioning is not required to drive the gases from the storage vessels to the distribution systems. These tanks can be delivered on fluids pallets on the Unpressurized Logistics Carrier or in a fluids rack within the Pressurized Logistics Carrier.

Liquids or supercritical cryogens, as in the case of helium, can be supplied to the Space Station more efficiently than gases because their densities are greater. Distribution of these fluids is not as simple as distribution of gases. Fluid conditioning is required to convert them to gases for use in the experiments. Storing the fluids in these condensed states requires moderate to high pressures and low temperatures, as well as some type of cooling mechanism for temperature maintenance. The following descriptions make no distinction as to whether the fluids arrive at the station as gases, liquids, or supercritical cryogens; they do assume the fluids being transferred to the distribution systems are gases.

Figure 3.4-3 shows a supply system for one fluid using the fluid rack for storage in the modules. This is similar to the baseline configuration and uses the fluids rack as both the transport structure and the storage volume for the gases.

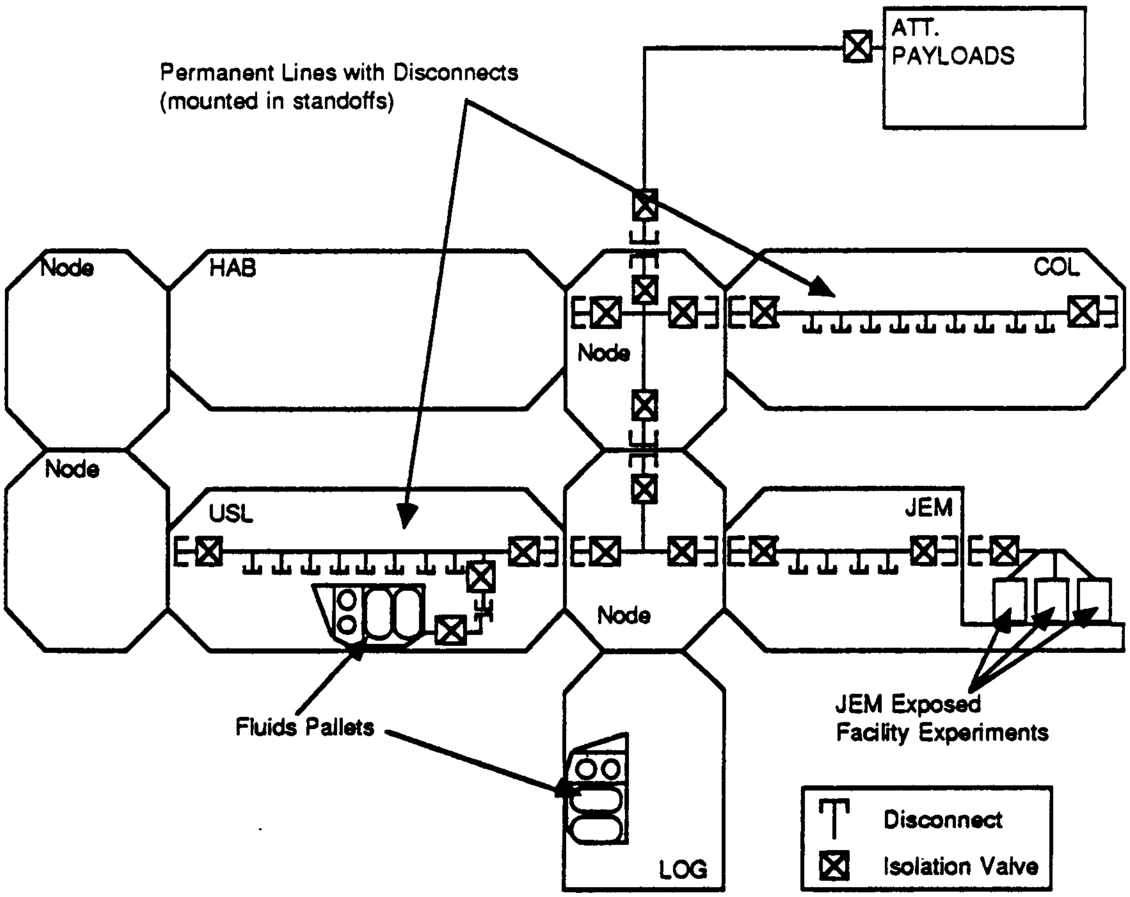

Figure 3.4-3 Fluids Rack Supply Configuration

Delivering fluids to the Space Station on a fluids pallet which is brought up on the Unpressurized Logistics Carrier (UPC) simplifies distribution to the attached payloads. This approach does not require penetrations of the pressure shell between the storage vessel and the attached payloads. The fluids pallet is attached to the Space Station truss structure. Fluid lines connect the tanks mounted on the pallet to both the attached payloads and to the modules. Penetrations of the pressure shell are required at one of the unused module interfaces to transfer the gases inside the modules for use in the laboratories. Insulation and debris protection are required for the tanks and any lines which are outside of the modules. A diagram of this system for one fluid is shown in Figure 3.4-4.

Resupply of gases to the Space Station from tanks permanently mounted on the Pressurized Logistics Carrier requires penetrations of the pressure shell at both the PLC docking interface and an unused module interface of one of the nodes. Figure 3.4-5 shows how this configuration uses the same distribution systems used with the fluids rack supply configuration. This system may not make good use of the tankage on the PLC because the tanks may not be completely emptied before the PLC is due to be returned to Earth.

A decrease in the total amount of fluid supplied to the Space Station may be achieved by recycling pure gases which have been discarded by the attached payloads. The current data available on the attached payload experiments which use argon and helium provides no information about the state in which these gases are supplied to the experiments or about the purity of the gases being

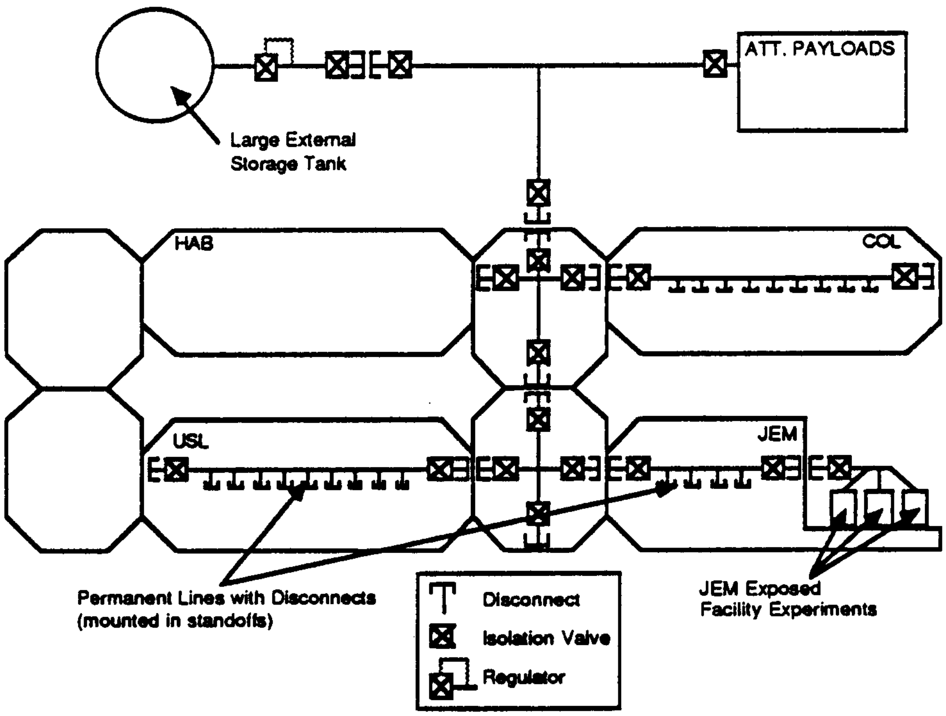

Figure 3.4-4 Fluid Supply System Using External Tankage on a Fluids Pallet (with Permanent distribution System)

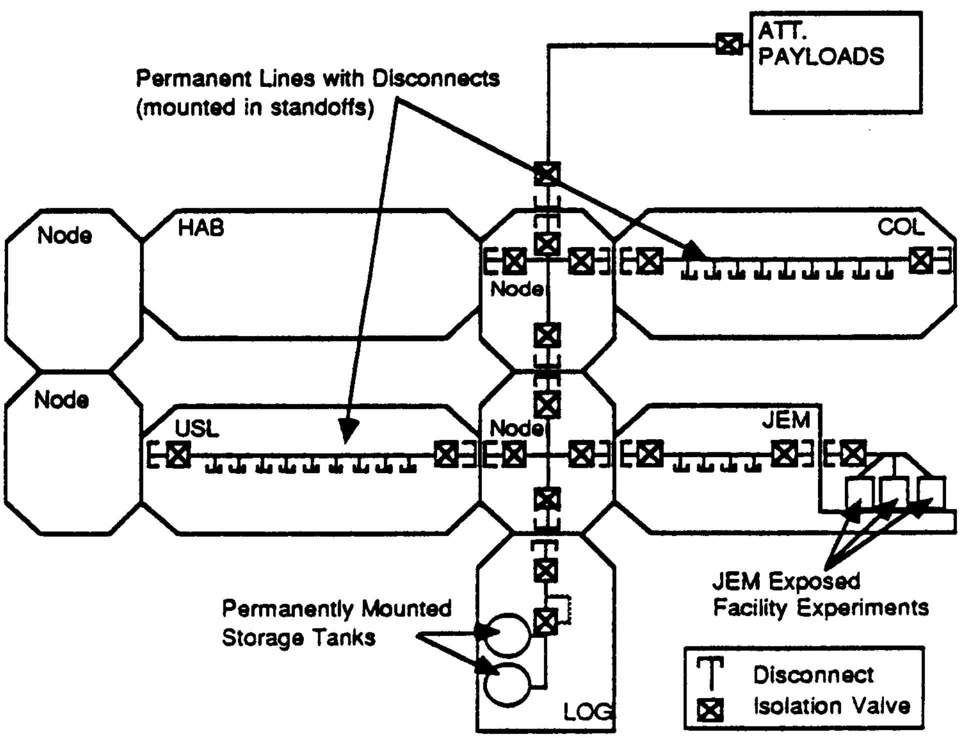

Figure 3.4-5 Resupply from Tanks Mounted in the Logistics Module

expelled from them. If the effluent gases are pure, they can be collected and compressed back into their respective distribution systems. This procedure, depicted in Figure 3.4-6, cuts down on the total amount of fluid which is being delivered to the Space Station without affecting any of the experiments. The only additional hardware required by these systems are the compressors required for recycling. Gas disposal lines are already required to avoid contamination of the environment.

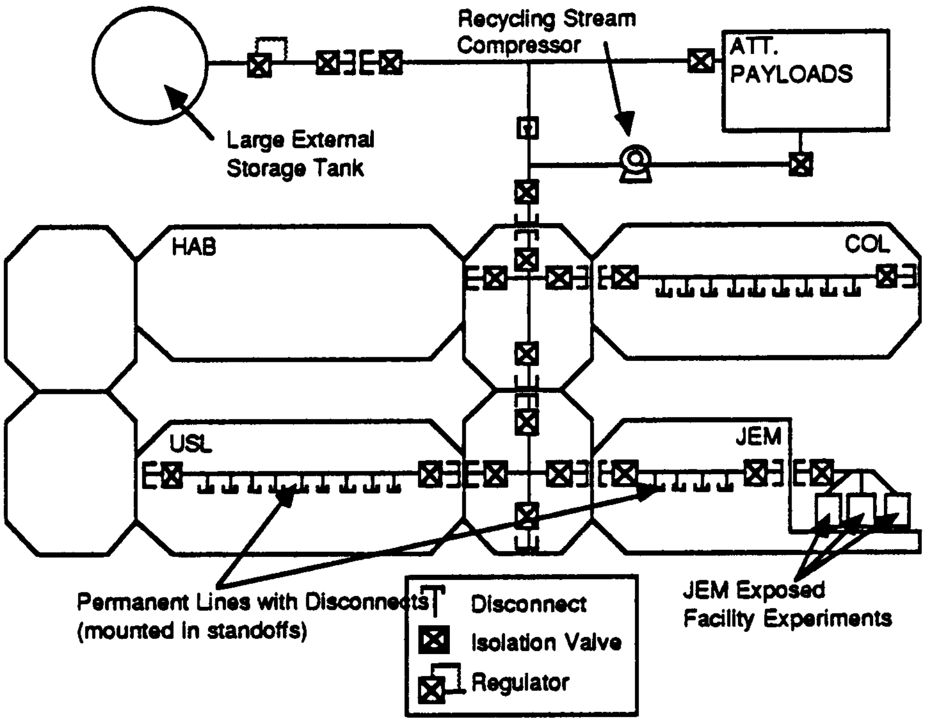

Figure 3.4-6 Reuse of Gaseous Waste from Attached Payloads

3.4.2.3 <u>Distribution Configurations for Integrated Systems</u> - Argon, carbon dioxide, and helium are required by all three laboratories, while only helium and argon are needed by the attached payloads. Distribution of the gases to the laboratories can be accomplished using either internal or external distribution lines or portable pressure tanks. A permanent internal distribution system requires installation of fluid lines within the utility runs of the nodes and modules as shown previously in Figure 3.4-2. Because provisions must be made for access to the fluid supply lines in any rack, permanent installation requires either a disconnect or a flex hose and disconnect for each fluid at each rack location. This type of system will require a large number of disconnects above and beyond the baseline quantity to connect the lines from module to module, and will also require space in the standoffs. A simple schematic of this configuration is shown in Figure 3.4-7. The argon and helium required by the attached payloads is piped directly to them through external lines which have both thermal and debris protection.

A permanent distribution system with external lines requires more insulation and debris protection hardware than a system with internal lines because of the greater amount of hardware it has that is exposed to space. There are fewer disconnects required, but assembly must take place on orbit and some room may still be required in the standoffs. Additionally, the disconnects are connections from the module to external lines, which require the manufacture of an additional penetration in each module's pressure shell. This configuration also transfers fluids directly to the

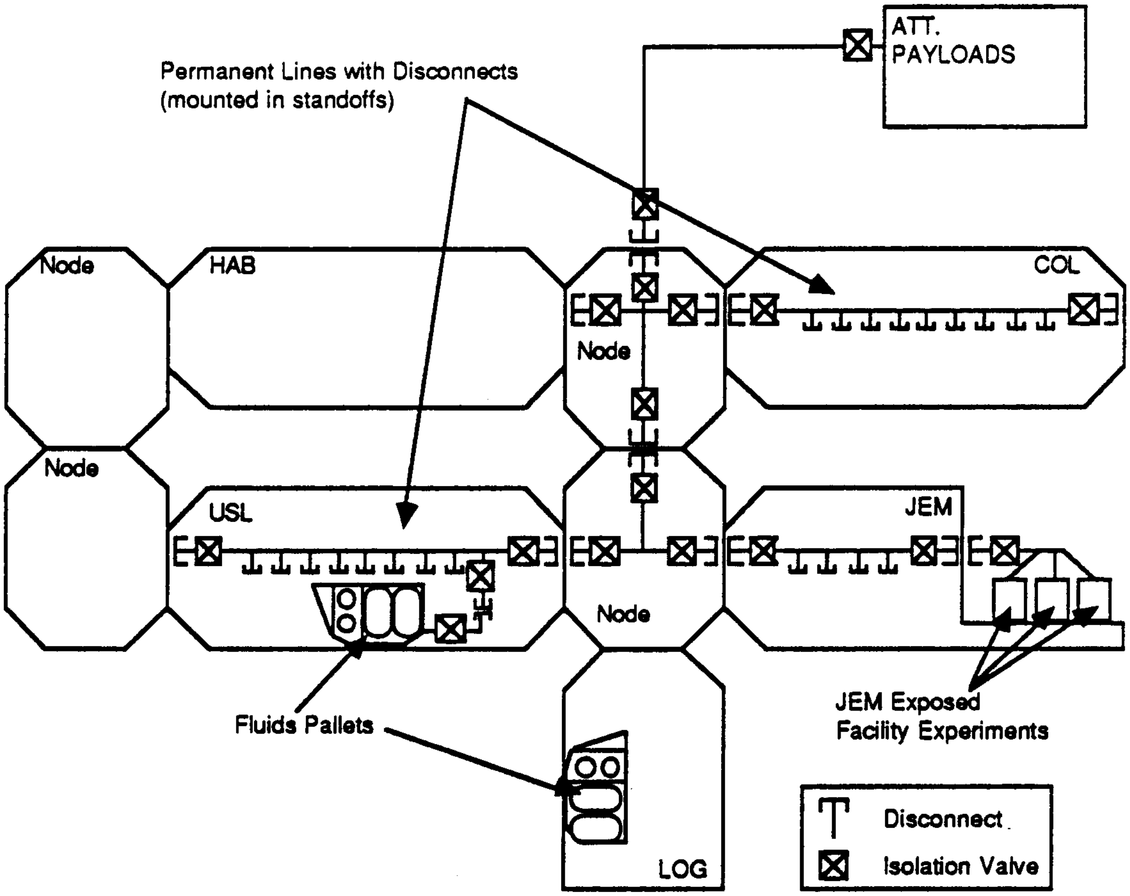

Figure 3.4-7 Permanently Mounted Gas Distribution System Schematic

attached payloads through external lines.

A flexible temporary system using lines that are not installed permanently in the standoffs can provide an alternative to the scarring required with permanent lines. These lines can be connected on one end to a disconnect at a supply source and at the other end to a disconnect on an experiment rack. The hoses can be moved from one experiment to another and after each move attached to the cabin walls by Velcro or other fasteners. Attaching the hoses to the wall prevents obstruction of the passageways. There may have to be several supply source disconnects for each fluid and even different supply locations in order to accommodate closed hatch operations by some of the users, i.e. the Japanese Experimental Module. These requirements may create a need for a hybrid temporary/permanent system which would include supply sources in each of the laboratory modules.

Pressure vessels can be used within the Space Station to provide the necessary flexibility for supplying the experiments with gases, but these vessels need not be returned to Earth for refilling. Refill of these small tanks can be performed on-orbit from a supply system which incorporates larger storage tanks for supply from Earth. The use of these larger tanks increases the mass fraction of supplied gas, which serves to decrease launch costs. Refill of the small pressure vessels can be performed by attaching them to a conveniently located disconnect, opening isolation valves on either side of the disconnect, and filling the tank to the desired pressure. More than one of these refill stations can be installed in one central location or at convenient spots throughout the modules.

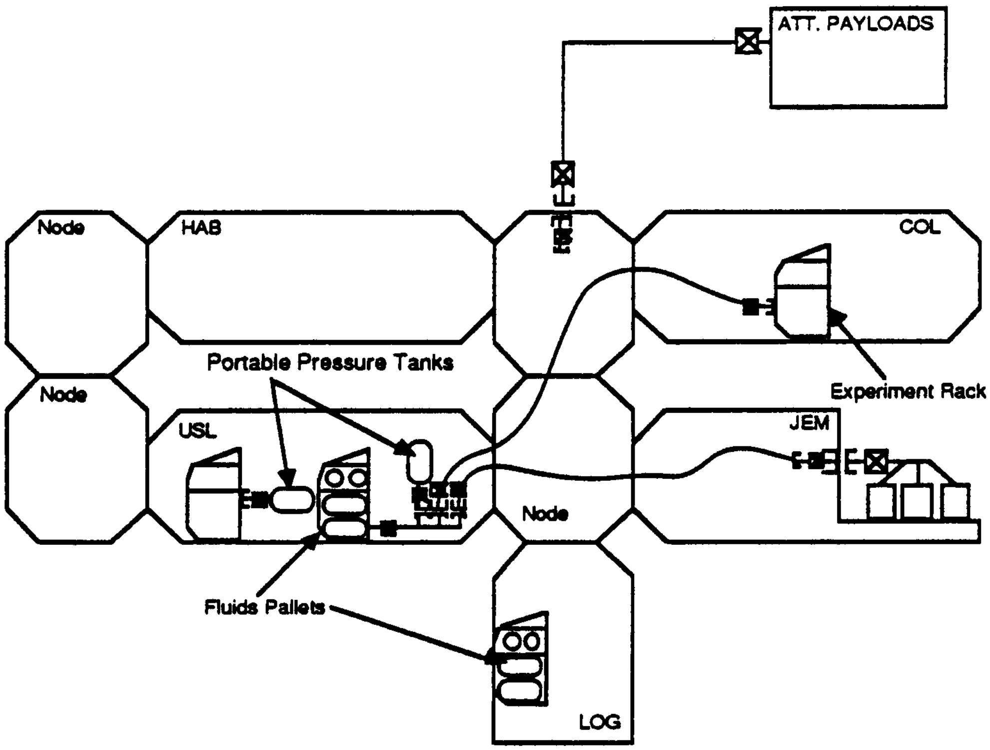

Figure 3.4-8 Distribution System Schematic with Temporary Supply Lines

A combination of the temporary line system and the portable tank system can provide the flexibility needed for closed hatch operations. This configuration is shown in Figure 3.4-8. The movable lines would be used for all but closed hatch operations, when portable pressure tanks would be used to supply those experiments that would be isolated. This combined system eliminates the need for constructing permanent lines to more than one location within the Space Station. However, the use of flex lines which pass through the hatches presents a problem with rapid egress requirements. This problem limits the practicality of this configuration.

Open or closed-hatch operations can both be served using a concept with permanent lines in the nodes and flexible lines in the modules, as shown in Figure 3.4-9. This distribution system is suited to resupply from the Pressurized Logistics Carrier, from experient racks, or from external fluids pallets. This concept uses the baseline distribution system in the nodes while providing distribution system flexibility in the modules. Permanent lines in the utility runs with disconnects at the racks are alleviated to save space. It also eliminates the running of flexible lines in the nodes and between modules where safety hazards due to temporary lines may be imposed. With this system, a flexible line is connected to a disconnect at the module/node interface and routed to the experiment rack.

Growth and commonality considerations may also play a role in the design of the experiment gas distribution systems. If more laboratory modules requiring gas supplies are eventually added to the Space Station, distribution lines already available in the nodes will allow much simpler fluid connections and will avoid a great deal of on-orbit construction. Installing these lines prior to launch also eliminates development costs incurred in designing more than one type of node.

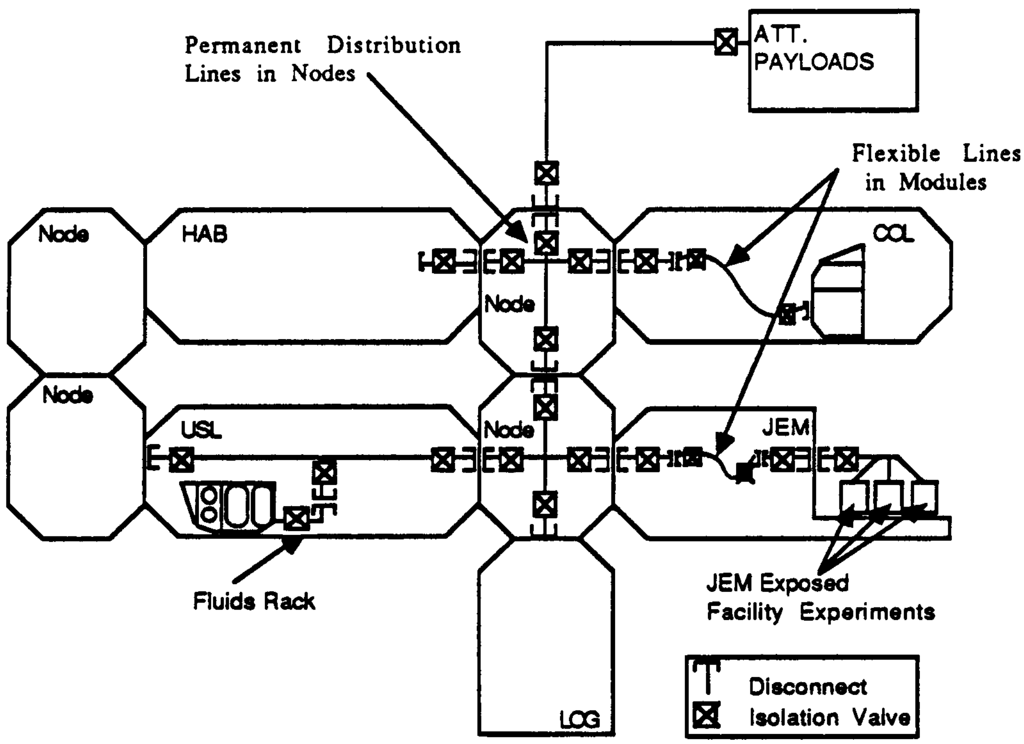

Figure 3.4-9 Temporary/Permanent Distribution System with Flexible Lines Within the Modules

3.4.2.3 Overall Configurations for Experiment Gas Supply - Several configurations have been developed to meet the supply requiremnts of all the experiment gas users. However, the overall optimum configuration for the Experient Gas Supply system has not been determined. Because of the large number of combinations of supply and distribution systems, the final selection will require more specific requirements about the number of users, usage timelines, supply pressures, and gas quantities.

3.5 INTEGRATED OXYGEN/HYDROGEN SYSTEM

There are several systems aboard the Space Station which use oxygen and/or hydrogen in their operation. There are also different sources for this oxygen and hydrogen. Table 3.5-1 contains a list of O_2 and H_2 users and sources.

Table 3.5-1 Oxygen and Hydrogen Sources and Users

Oxygen Users	Hydrogen Users
- ECLSS	- ECLSS
Crew (Respiration)	Sabatier CO_2 Reduction
Safe Haven Oxygen Supply	
HBC Operations	
Airlock Operations	
- Experiment Gas Supply	- Experiment Gas Supply
USL	USL
Columbus	Columbus
JEM	JEM
- Main O_2/H_2 Propulsion System	- Main O_2/H_2 Propulsion System
Oxygen Sources	**Hydrogen Sources**
- Water Electrolysis	- Water Electrolysis
	- ECLSS
	Bosch CO_2 Reduction

The reference configuration uses portable gas pressure vessels for supplying gases used for the experiments. Because these vessels tend to be rather heavy, eliminating the cost of launching them benefits the Space Station program.

The Environmental Control and Life Support Subsystem (ECLSS) uses a recycling process which produces oxygen and hydrogen from water that is brought up as part of the crew's food. The water is reclaimed by the life support system after it has been ingested and eliminated by the crew's bodies. This water is then electrolyzed to produce oxygen and hydrogen. The oxygen is used for respiration and much of the hydrogen is used in the CO_2 reduction processes.

There are two types of carbon dioxide reduction processes that are being studied for use on the Space Station, the Bosch and Sabatier processes. The Bosch reacts hydrogen with CO_2 to produce solid carbon and water, using most of the hydrogen in the process. The water is recycled and the carbon is returned to Earth on the Shuttle or deorbitted by other means. The Sabatier, on the other hand, reacts hydrogen with CO_2 to produce methane (CH_4) and water. All of the hydrogen is used up in this process without converting all the carbon dioxide. Again, the water is recycled. The remaining mixture of CO_2 /CH_4 is then discarded as waste or used for propulsion through resistojets. The quantities of the gases used and produced are discussed in Section 3.1.

The Propulsion System produces oxygen and hydrogen from water, also through the process of water electrolysis. The water used for this process must be obtained from the ground via the NSTS Shuttle or from one of the Space Station onboard systems, such as excess potable water from the ECLSS.

The Experiment Gas Supply provides oxygen and hydrogen, as well as other reagent gases to the experiments that require them. The reference configuration delivers oxygen and hydrogen in portable gas containers which are brought to the Space Station specifically for that purpose; however; these two gases may be obtained from electrolyzed water.

Water electrolysis is the process of breaking down water into its constituents by passing an electrical current through it. There are several types of apparatus for performing water electrolysis, but only two that are known to work in microgravity environments. These two types, which are currently being studied for use on the Space Station, are the Potassium Hydroxide Electrolysis Unit (KOH), and the Solid Polymer Electrolyte Electrolysis Unit (SPE). There are different schemes for using these units and different fluid conditions at which they will operate. The primary driver for the overall hydrogen/oxygen generation system is a need to store the gas at high pressure (1000 to 3000 psia) in order to reduce the storage tank volume and mass. Although the KOH unit operates with greater efficiency, the SPE electrolyzer may prove to be the better candidate because it can operate with a pressure rise across it, possibly allowing a high pressure outlet flow with a low pressure feed. Because of the design of the unit, the KOH electrolyzer cannot operate with a pressure rise across it.

3.5.1 Integration of the Oxygen and Hydrogen Supplies

The goal of integrating the oxygen and hydrogen supplies on Space Station into one system is to decrease the overall cost of providing the required Space Station functions. The specific savings achieved by integrating the oxygen and hydrogen systems come from decreasing the quantity of water that must be delivered to the Space Station, from eliminating the need for resupplying oxygen and hydrogen for experiment use, and from decreasing the amount of hardware that must be manufactured and launched.

An effective way of decreasing the amount of water that must be delivered to the Space Station is to increase the quantity of hydrogen in the oxygen/hydrogen propellant mixture. Additional hydrogen decreases the propellant mixture ratio of oxygen to hydrogen from 8 to 1 closer to a stoichiometric relationship which results in a more efficient chemical reaction in the O_2/H_2 thrusters and a higher specific impulse. The specific impulse, or I_{sp}, for O_2/H_2 thrusters has been demonstrated to vary from 380 sec at a mixture ratio of 8:1 to 420 sec at 6:1. Increasing the specific impulse of the propellants decreases the quantity of propellant which must be delivered to the Space Station. The hydrogen for increasing the I_{sp} can be obtained from the ECLSS if the Bosch carbon dioxide reduction process is used, or from the the excess hydrogen produced when water is electrolyzed to produce the required amount of oxygen for the experiments.

3.5.1.1 Integration Level Candidates - Three levels of system integration were developed for the oxygen/hydrogen system: non-integrated, partially integrated, and fully integrated. The three levels refer to the level of sharing of hardware and fluids. The non-integrated systems are entirely separate hardware and fluid systems. The partially integrated systems share hardware and/or fluids between the ECLSS and Propulsion systems but leave the Experiment Gas Supply as a completely seperate system. The reference system considered for this study was a partially integrated system. The non-integrated cases were included to show the quantity of the integraton benefits already achieved. The fully integrated systems share hardware and fluids among all three systems. The effects of all three integration levels on resupply and disposal quanities are shown in Table 3.5-2. The hardware descriptions included here are very brief and are only presented to illustrate the analysis of resupply and disposal quantities. A more complete evaluation of these hardware systems is included in EP 2.4, "Fluids Management System Databook." The option numbers included in parentheses at the end of each description refer to the schematics presented in the databook, while the lower case letters attached to them refer to the CO_2 reduction scheme.

The values in Table 3.5.2 were calculated using information on the ECLSS system mass balance as developed by Hamilton Standard and using propulsion impulse and experiment gas quantities as developed by Martin Marietta. The resupply values represent the combined quantity of those materials shown for all three systems. The disposal values reflect all the material that must be disposed of, with the exception that systems using the Sabatier process are not penalized for non-propulsively venting CO_2 /CH_4 mixture, due to the small expense required relative to deorbit costs.

Table 3.5-2 Consumables Resupply and Waste Disposal
(All masses are in lb_m per 90 days)

Integration Level	Version	Resupply			Disposal				Total*
		Water	Gases	Total	C(s)	CO_2/CH_4	H_2O	Total*	
Non-integrated									
Bosch	1	2932	209	3141	436	—	670	1106	4247
Sabatier	2	2932	209	3141	—	958	186	186	3327
Partially integrated									
Bosch (shared water only)	1	2263	209	2472	436	—	—	436	2908
Bosch	2	2081	209	2290	436	—	—	436	2726
Sabatier	3	2731	209	2940	—	958	—	0	2940
Sabatier w/ CO_2/CH_4	4	2380	209	2589	—	—	—	0	2589
Fully integrated									
Bosch	1	2200	—	2200	436	—	—	436	2636
Sabatier	2	2854	—	2854	—	958	—	0	2854
Sabatier w/ CO_2/CH_4	3	2504	—	2504	—	—	—	0	2504

* Does not include waste CO_2/CH_4 (No penalty for waste vented non-propulsively)

The relative cost of launching and deorbitting materials used on the Space Station has not yet been determined. A figure of approximately $3000 per pound launched was used in many of the Phase B Space Station trade studies with no figure set for the cost of returning materials to Earth. Because of the restrictions on Shuttle landing weight, the cost of deorbiting materials may exceed that of launching them. In this section the data is presented only in terms of mass. The last column in Table 3.5-2 is a total of all masses (relevant to this study) that must be transported to and from the Space Station. Given a one to one ratio of launch to deorbit costs, this column would show which system is the least costly to operate.

3.5.1.3 Non-Integrated Systems - Analysis was performed for two versions of the non-integrated level. The first is a system which uses the Bosch CO_2 reduction process. This process produces solid carbon which must be returned to Earth in the Shuttle or deorbitted by some other method. In addition, the Bosch process produces a large quantity of excess potable water which, in the non-integrated case, must be disposed of. Because of the large quantity of this water it cannot be vented and must be deorbitted by some means. (option 1a)

The second version of the non-integrated level is a system which uses the Sabatier CO_2 reduction process. This process produces no solid carbon, instead it produces a mixture of carbon dioxide and methane as mentioned previously. This mixture can be stored and then vented when allowable. The cost of storing the mixture is insignificant relative to deorbit costs (unless they are zero) and is not figured into the transported total. The Sabatier process also produces a quantity of excess potable water, although it is much smaller than that from the Bosch. These facts lead to the conclusion that the Sabatier is a better choice when no integration is employed. (option 1b)

3.5.1.4 Partially Integrated Systems - Four versions of the partially integrated level were examined. The first version is in essence the same as the non-integrated Bosch example, with a water line added for transferring excess potable water from the ECLSS to the propulsion system. The water transferred makes no change in the operating characteristics of the system, it simply reduces the total quantity of water that must be supplied to the station by the amount shared and eliminates the need to deorbit waste water. The carbon produced is still a waste product and must be disposed. This is the reference system for the cost comparison in Section 3.5.2. (option 2a)

Identical values of the resupply and disposal figures for the second version of the partially integrated level are obtained by analyzing two very different hardware systems. These systems both share water and hydrogen between the Bosch ECLSS and the Propulsion system. The difference lies in the level of hardware integration of the two systems. One system is much like the first partially-integrated version, using separate hardware systems which share fluids through transfer lines. In this case the excess hydrogen produced by the ECLSS is piped to the Propulsion system where it lowers the mixture ratio, and consequently reduces the amount of propellant required. This decreases both the launch and disposal costs. Only the solid carbon must be disposed of. The hardware costs remain essentially the same with slight additional expenses incurred for the hydrogen and water lines. (option 3)

The other hardware system which produces the second version results is a system which not only shares fluids, but also electrolysis units, dryers, and water storage facilities. Again the mixture ratio of the propellant gases is decreased, lowering the water resupply requirement. The carbon remains as waste and must be eliminated. This type of integration greatly decreases the cost of hardware by eliminating duplication. (options 4a,5a,6a)

The results for the third version of the partially integrated level are also produced using two different hardware systems which use the Sabatier CO_2 reduction process. One system is identical to the non-integrated Sabatier concept, with a water line added to transfer the excess water produced by the ECLSS to the propulsion system for use as propellant. As in the non-integrated case, disposal of the CO_2/CH_4 mixture produced is not penalized because of the ease with which it can be accomplished. This version recieves no benefit from integrating hydrogen systems since the Sabatier process gives off no excess hydrogen. (option 2b)

These same resupply and disposal results are also obtained from a hardware system which shares electrolysis units, dryers, and water storage facilities in addition to the fluids it shares. This level of hardware integration decreases the number of components which must be constructed, which lowers initial cost. (options 4b,5b,6b)

The fourth version of the partially integrated level is identical to the third with one exception. Again the same results apply to two hardware systems using Sabatier CO_2 reduction, one which only shares fluids, the other which shares fluids and hardware; however, the CO_2 /CH_4 mixture is used in resistojets as a propellant to reduce overall resupply requirements. Although the mixture doesn't produce a great deal of impulse per given weight, the large quatity of it which is available produces a large amount of impulse. As shown in Table 3.5-1, the use of this thrust greatly decreases water delivery requirements, lowering operational costs. (option 2c, options 4c,5c,6c)

3.5.1.5 Fully Integrated Systems

Three versions of the fully integrated level were analyzed. All three are very similar to those partially integrated level hardware systems in versions two, three, and four which share hardware. However, the fully integrated versions also integrate the Experiment Gas Supply by using the electrolysis units to produce O_2 and H_2 for the experiments from water brought up instead of

gases. Electrolyzing the correct quantity of water to produce enough oxygen for the experiments produces more hydrogen than can be used by them. Including this hydrogen in the propellant supply reduces the mixture ratio, raises the I_{sp}, and lowers the quantity of water that must be electrolyzed for propellant. This integration also eliminates the need for oxygen and hydrogen storage tanks and associated hardware, further reducing cost.

3.5.2 Integrated Hardware System Candidates

Nine candidate systems were evaluated to determine the optimum candidate for the integrated oxygen/hydrogen propulsion system, based on life cycle cost. The schematics that were developed for these nine "options" are presented in EP 2.4, the "Fluids Management Systems Databook" in Figures 4.1-1 through 4.1-9. Table 3.5-3 matches these options with the proper versions of the system integration levels.

Table 3.5-3 Relationship Between O_2/H_2 Integration Levels and Hardware System Schematics

Integration Levels	Version	CO_2 Reduction	Shared Entities	Schematic (Option)
Non-integrated	1	Bosch	None	1a
Non-integrated	2	Sabtier	None	1b
Partially integrated	1	Bosch	H_2O	2a
Partially integrated	2	Bosch	H_2O, H_2	3
Partially integrated	2	Bosch	Hdwr, H_2O, H_2, O_2	4a,5a,6a
Partially integrated	3	Sabatier	H_2O	2b
Partially integrated	3	Sabatier	Hdwr, H_2O, H_2, O_2	4b,5b,6b
Partially integrated	4	Sabatier	H_2O, CO_2/CH_4	2c (+ R-jets)
Partially integrated	4	Sabatier	Hdwr, All fluids*	4c,5c,6c (+ R-jets)
Fully integrated	1	Bosch	Hdwr, H_2O, H_2, O_2	7a,8a,9a
Fully integrated	2	Sabatier	Hdwr, H_2O, H_2, O_2	7b,8b,9b
Fully integrated	3	Sabatier	Hdwr, All fluids*	7c,8c,9c (+ R-jets)

* All fluids includes H_2O, H_2, O_2, CO_2/CH_4 mixture.

3.5.3 Cost Assessment of the Integrated Oxygen/Hydrogen System

The Integrated Cost Model which was developed in Task I of this program for propulsion systems was used to evaluate the Integrated O_2/H_2 System concepts described above. This cost model analysis included costs for initial hardware, spare parts, launch, maintenance, fluid resupply, and waste deorbit. The cost model software includes capabilities for calculating software and assembly costs, but these were omitted due to the uncertainty of the quantity of each required. These omissions were assumed to make little or no difference between the candidates due to the similarities in the systems. The only case where inconsistencies in the evaluation may have occurred due to these omissions was in the ground assembly costs; however, these costs were still assumed to be insignificant due to their relatively low cost.

Costs were analyzed using the parts lists and resupply/disposal masses discussed in Section 3.5.1. Twenty-four combinations were identified as shown in the Schematic (Option) column of Table 3.5-3. The cost model was run for each of these combinations. The results of the cost model comparison are shown in Table 3.5-4, including initial, operating, life cycle (initial plus operating), and relative cost. The baseline for the relative costs was Option 2a, the reference system identified in Section 3.5.1.4. Option 2a is a partially integrated system which integrates fluids only by piping excess water from the ECLSS to the propulsion system.

Life Cycle Cost (LCC) was the basis on which this study determined the optimum O_2/H_2 system configuration. The two costs which contribute to Life Cycle cost are Initial Operating Configuration (IOC) cost and Operating cost. IOC Cost includes hardware costs with wraparounds, launch costs, and assembly costs. Operating cost includes spare parts and propellant resupply costs along with associated launch costs, maintenance costs, and waste deorbit costs. As can be seen in Table 3.5-4, the major contributor to LCC is Operating cost.

Table 3.5-4 Results of the Cost Comparison for 24 Integrated O_2/H_2 Systems (Millions of Dollars)

Option Number	IOC Cost	Operating Cost	Life Cycle Cost	% of Baseline LCC Cost
1a	134.40	771.53	905.93	130.0%
1b	134.40	627.40	761.80	109.3%
2a	135.03	562.00	697.03	100.0%
2b	135.23	567.09	702.32	100.8%
2c	155.74	518.28	674.02	96.7%
3	141.14	534.73	675.87	97.0%
4a	112.40	524.26	636.66	91.3%
4b	112.21	557.73	669.94	96.1%
4c	132.53	508.83	641.36	92.0%
5a	113.53	521.60	635.13	91.1%
5b	113.33	555.07	668.40	95.9%
5c	133.65	506.18	639.83	91.8%
6a	105.96	521.75	627.71	90.1%
6b	105.77	555.22	660.99	94.8%
6c	126.09	506.32	632.41	90.7%
7a	.103.73	457.82	561.55	80.6%
7b	103.01	492.53	595.54	85.4%
7c	123.41	443.05	566.46	81.3%
8a	107.35	456.82	564.17	80.9%
8b	106.63	490.76	597.39	85.7%
8c	127.04	442.05	569.09	81.6%
9a	99.75	455.31	555.06	79.6%
9b	99.03	489.25	588.28	84.4%
9c	119.43	440.54	559.97	80.3%

3.5.2.1 Effect of Integration Level on Life Cycle Cost

The graphs in Figures 3.5-1 through 3.5-5 show the effect the amount of integration has on the cost of constructing, building, and using systems to perform ECLS, propulsion, and gas supply functions on the Space Station. These three figures show how integration affects costs for systems using the three carbon dioxide reduction schemes, Bosch, Sabatier, and Sabatier using waste CO_2/CH_4 in resistojets. The cost savings realized from increasing the level of integration must be examined separately for IOC and Operating costs.

IOC cost reflects the level of hardware integration that has been achieved. As can be seen in Figure 3.5-1, Options 1a, 2a, and 3 have approximately the same IOC cost , then there is a drop between them and Options 4a, 5a, and 6a. This drop reflects the reduction in the total number of electrolysis units and water storage tanks required. A smaller level of savings is realized for Options 7a, 8a, and 9a because of the elimination of separate gas storage tanks. These savings are not associated with the operating characteristics of the system and therefore do not fall along the lines of the Non-Integrated, Partially Integrated, and Fully Integrated breakdown. Similar effects

are seen for systems using the other CO_2 reduction schemes and are shown in Figures 3.5-4 and 3.5-5.

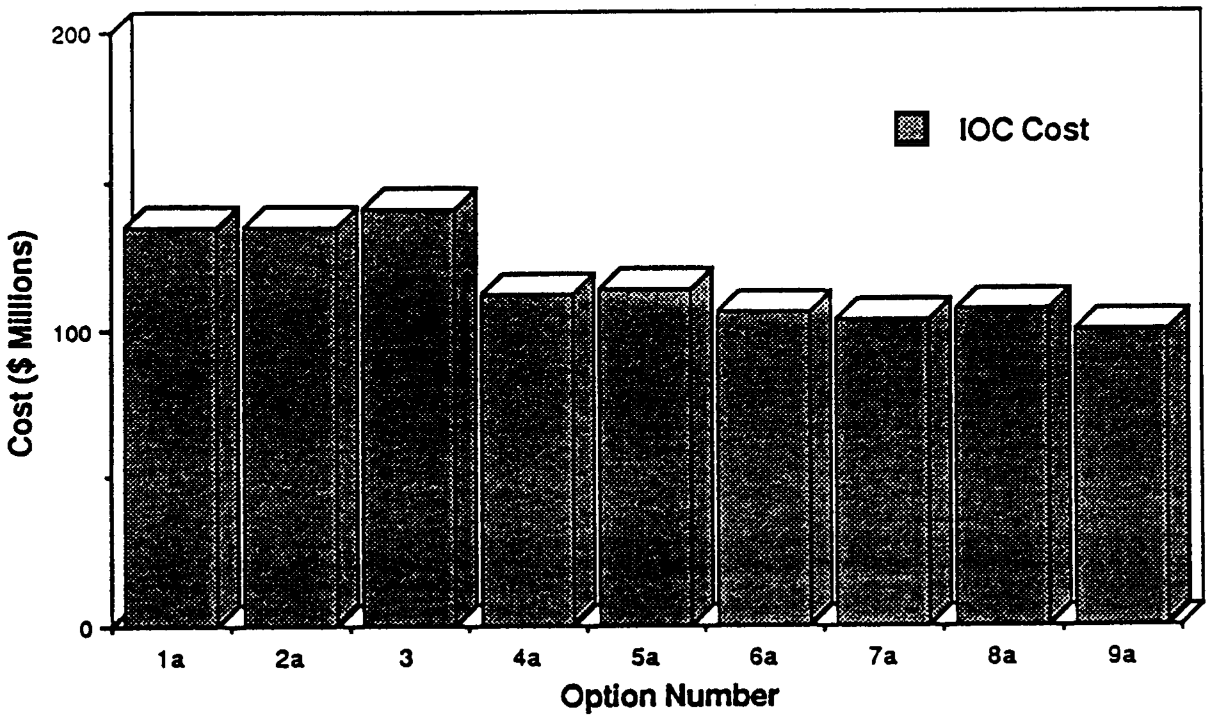

Figure 3.5-1 IOC Cost for Bosch Systems

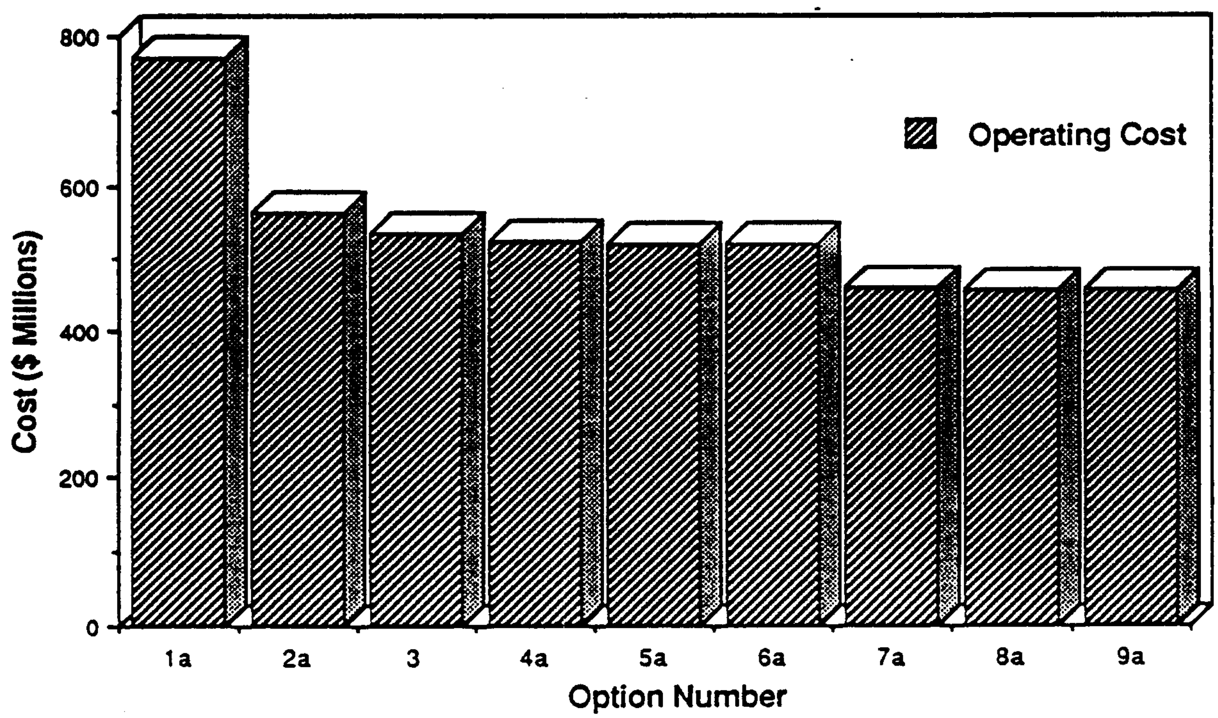

Figure 3.5-2 Operating Cost for Bosch Systems

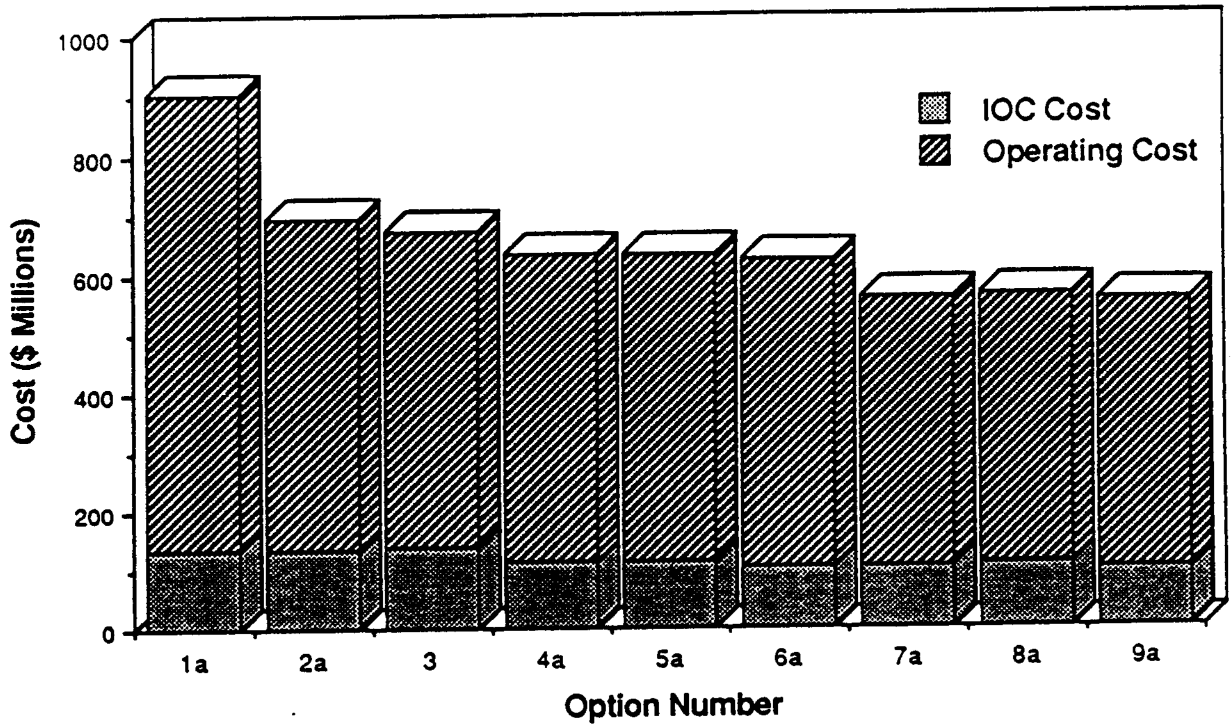

Figure 3.5-3 LCC Cost for Bosch Systems

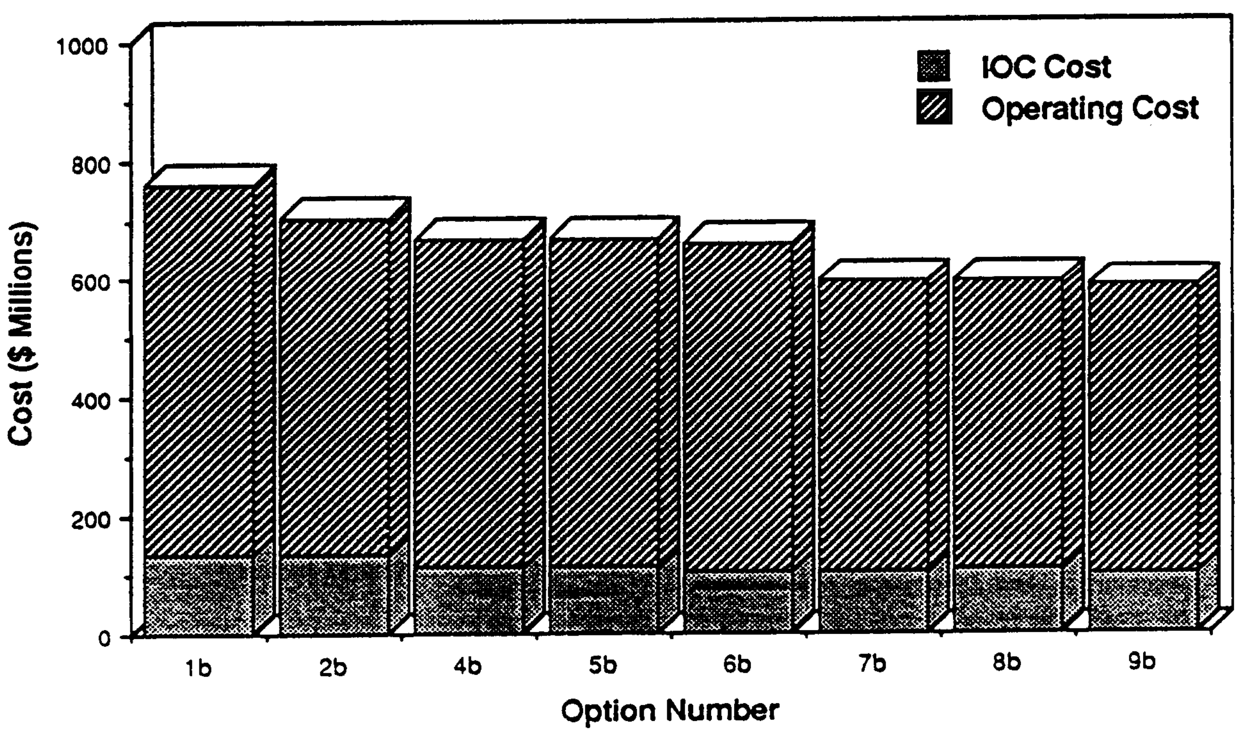

Figure 3.5-4 LCC Cost for Sabatier Systems

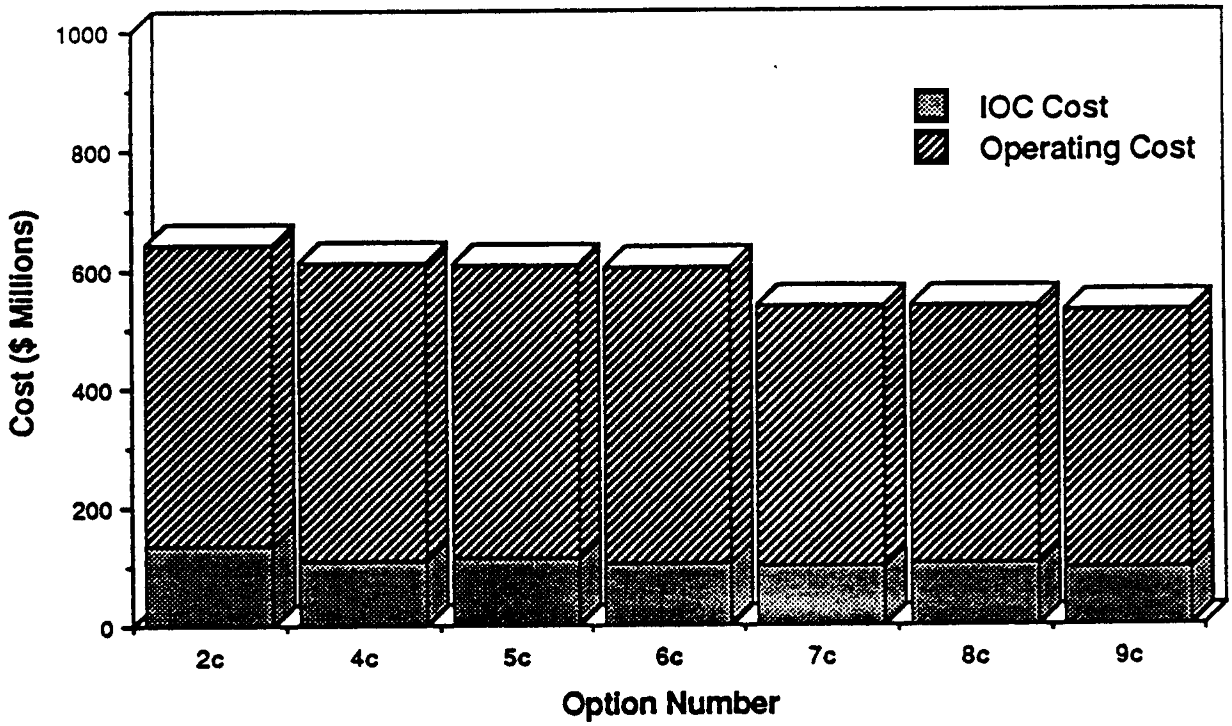

Figure 3.5-5 LCC Cost for Sabatier with Resistojets Systems

The level of fluids integration achieved is reflected in the Operating cost. The graph in Figure 3.5-2 shows the great cost savings obtained by sharing the excess water from the ECLS with the Propulsion system. This is a direct result of both the reduction in total water quantity that must be delivered to the Space Station, and the elimination of the requirement to deorbit any waste water. This is shown by the step down from Option 1a to Option 2a. The next step down in Operating cost is from Option 2a to Option 3, which corresponds to the savings achieved by using waste H_2 from the ECLSS to increase the specific impulse of the propellants for maneuvering. As can be seen in the graph, there is a small step down from Option 3 to Options 4a - 6a. This savings is the result of maintaining less hardware for the latter three systems. The large jump down from Options 4a - 6a to 7a - 9a is the result of using excess hydrogen for propulsion functions. This additional excess H_2 is the by-product of electrolyzing water to provide oxygen for experiments. The same changes are apparent in Figures 3.5-4 and 3.5-5 for systems using other CO_2 reduction schemes.

Figure 3.5-3 combines the IOC and Operating costs for the Bosch systems to arrive at the Life Cycle cost. The addition of the two types of costs leads to several combinations, all of which show that as systems become more integrated their costs go down. The same trend is also shown for Life Cycle costs for both Sabatier and Sabatier with resistojets systems in Figures 3.5-4 and 3.5-5.

3.5.2.2 <u>Effect of Carbon Dioxide Reduction Process on Life Cycle Cost</u>

Figure 3.5-6 shows the IOC and Operating costs for options 4a, 4b, and 4c which represent systems using Bosch, Sabatier, and Sabatier with resistojets, respectively. This representative option shows that the costs for an individual option are similar; however, the variations are consistent throughout the different options.

The IOC cost for the Sabatier with resistojets system is higher than those for the Bosch and Sabatier concepts because of the cost that is incurred to install the resistojet system. Otherwise, the three systems are very similar with hardware variations only in the size of the storage tanks.

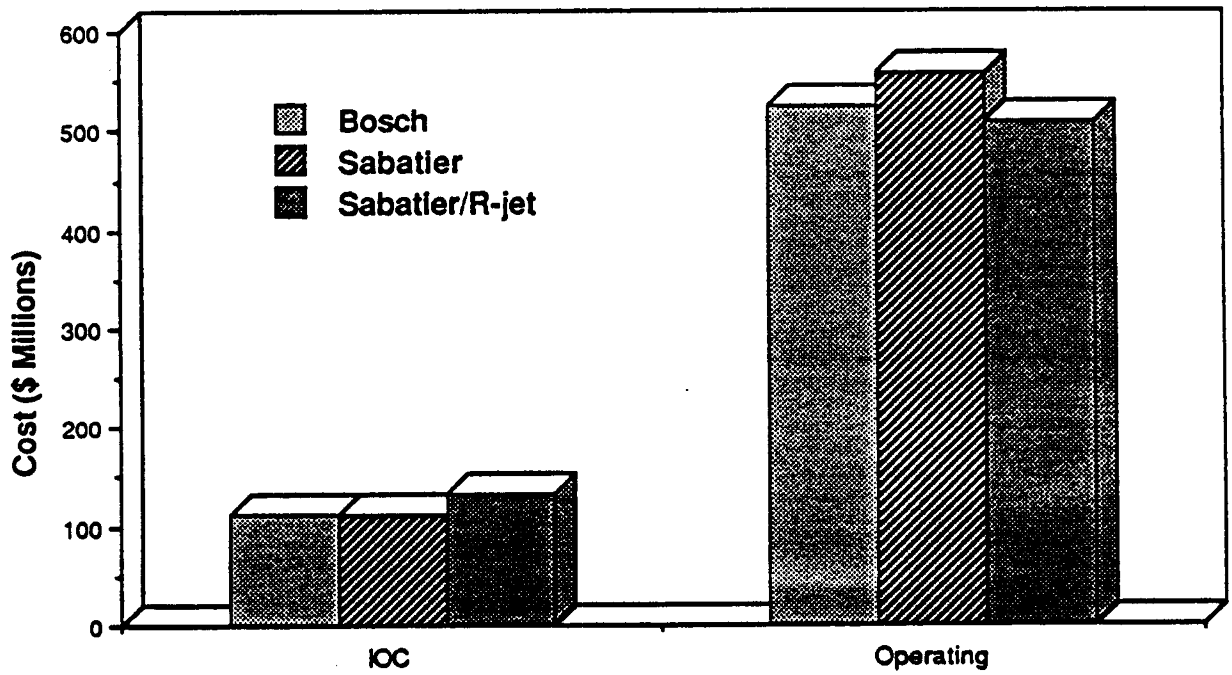

Figure 3.5-6 Comparison of IOC and Operating Costs for the Three Carbon Dioxide Reduction Schemes

The Operating costs for the three types of systems also vary in a fairly consistent manner among the various options. Because the Bosch ECLSS provides excess hydrogen to the propulsion system, the cost of operating it is less than that of the Sabatier, even when taking into account the need for solid carbon to be deorbited when using the Bosch. The use of resistojets to propulsively dispose of waste CO_2/CH_4 from the Sabatier ECLSS provides the savings shown for the Sabatier with resistojets system by decreasing the amount of water that must be supplied for propulsion.

4.5.2.3 Overall Effects of Integration on Life Cycle Cost - Figure 3.5-7 shows the Life Cycle costs for all 24 options that were analyzed in this study. This graph combines the effects shown previously and displays them in such a way as to demonstrate the optimum system. The optimum system, as shown both graphically in Figure 3.5-7 and numerically in Table 3.5-5 above, is Option 9a, the Fully Integrated Bosch system with a pumping electrolysis unit. However, the cost difference between this system and its closest followers is not large enough to set it apart as the clear "winner," due to the possible errors introduced in the assumptions. Any one change in the assumptions could change the ranking among systems.

The general trend shown in Figure 3.5-7 is that as systems become more integrated, they also become less expensive to build and operate. This is in essence the desired outcome from this comparison; the actual results as to the exact configuration of the optimum system are only a by-product and are so close as to not provide a definite solution.

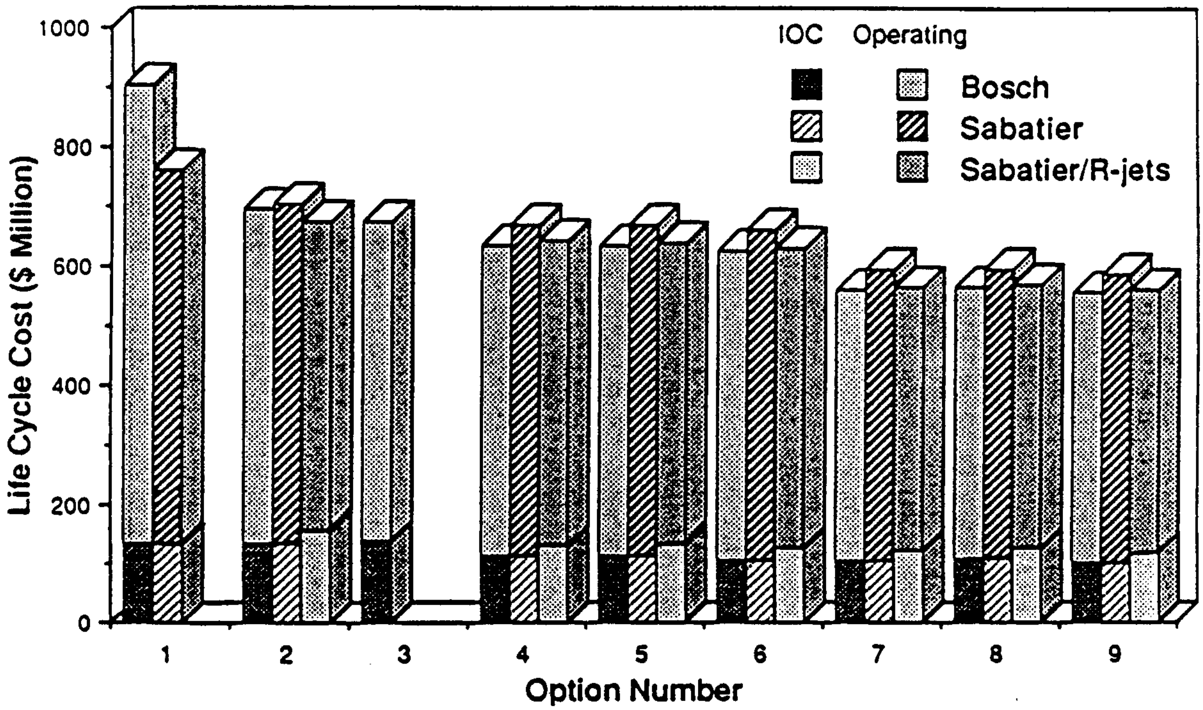

Figure 3.5-7 Effect of Integration on LCC Cost for O_2/H_2 Systems

3.6 INTEGRATED WATER SYSTEM

A system level investigation of an Integrated Water System (IWS) was performed to evaluate the benefits of such a concept. Tasks required to define the system included 1) an investigation into the National Space Transportation System (NSTS) Shuttle potable water generation and the availability of this water for transfer to the Space Station, 2) definition and evaluation of potable water storage concepts for the Space Station, 3) identification of water resupply requirements and evaluation of concepts for meeting these requirements, and 4) definition of Space Station water distribution options. Discussions of water quality monitoring and decontamination issues are discussed in detail in EP 2.4, "Fluids Management System Databook."

3.6.1 Water Sensitivity Analysis

A water sensitivity analysis was conducted at the beginning of the study to define the relative importance of the factors which affect the amount of water on the Station and its distribution. Parameters investigated in this analysis include the following:

1) Bosch CO_2 reduction,
2) Sabatier CO_2 reduction,
3) Interaction of the NSTS crew on board SS,
4) NSTS fuel cell water - availability and quantity,
5) Extra-Vehicular Activity (EVA) water requirements,
6) SS crew food water content,
7) Resupply period,
8) Integration of the Japanese Experiment Module (JEM) and Columbus (COL) water requirements and,
9) United States Laboratory (USL) water requirements.

The sensitivity analysis was conducted using a Microsoft Excel spreadsheet program on a Macintosh Plus personal computer. The spreadsheet format, baseline input parameter values, and baseline water balance are shown in Figure 3.6-1. The spreadsheet inputs that affect the balance

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2407
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1165
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

Figure 3.6-1 Water Balance Sensitivity Analysis -- Baseline

are SS crew size, length of time the orbiter is docked to the SS, the number of orbiter crew members who use the Station facilities, orbiter fuel cell average power level while docked, SS crew food water content, the CO_2 reduction process, and laboratory experiment water requirements. The computed results include the quantities of Environmental Control and Life Support System (ECLSS) excess potable water, NSTS generated ultrapure and waste water, and EVA and experiment water requirements. The laboratory water requirements are subtracted from the excess potable water to determine the total excess water available for use in the propulsion system. The ECLSS excess water generation rate was computed using the MACMIMBA computer program[8] with input parameters supplied by Hamilton Standard[9]. The baseline balance gives a total excess water amount of 1165 lbm per 90 days. This study did not take into account the propellant savings associated with using excess hydrogen to augment the propulsion capabilities, nor did it include the benefits of integrating the oxygen and hydrogen requirements of the experiments as described in Section 3.5.

The sensitivity analysis was carried out by varying each parameter by a consistent amount. The majority of the sensitivity parameters were varied by the same percentage of 25%. This was done in order to observe the effect changing a single parameter had on the total amount of excess water generated, relative to a similar change in each other parameter. In some cases, such as Bosch or Sabatier CO_2 reduction and Advanced Extravehicular Mobility Unit (EMU) or NSTS EMU, this was not possible. In those cases the changes are discreet and cannot be varied by a certain percentage. The result of the sensitivity analysis is seen in Figure 3.6-2. The total excess water generated for each sensitivity parameter is plotted and compared to the baseline. To complement Figure 3.6-2, the percentage change in excess water from baseline for each parameter is shown in Figure 3.6-3. This gives a graphic portrayal of the parameters that affect the water balance. Using the Sabatier CO_2 reduction process the excess water decreases by 45.5%. Increasing the time the shuttle is docked to the SS by 25% increases the amount of excess water by 35%. Integrating the JEM waste water system or increasing the number of NSTS crew on the Station has a small effect on the water balance. Alternatively, implementing a 90 day resupply interval has a

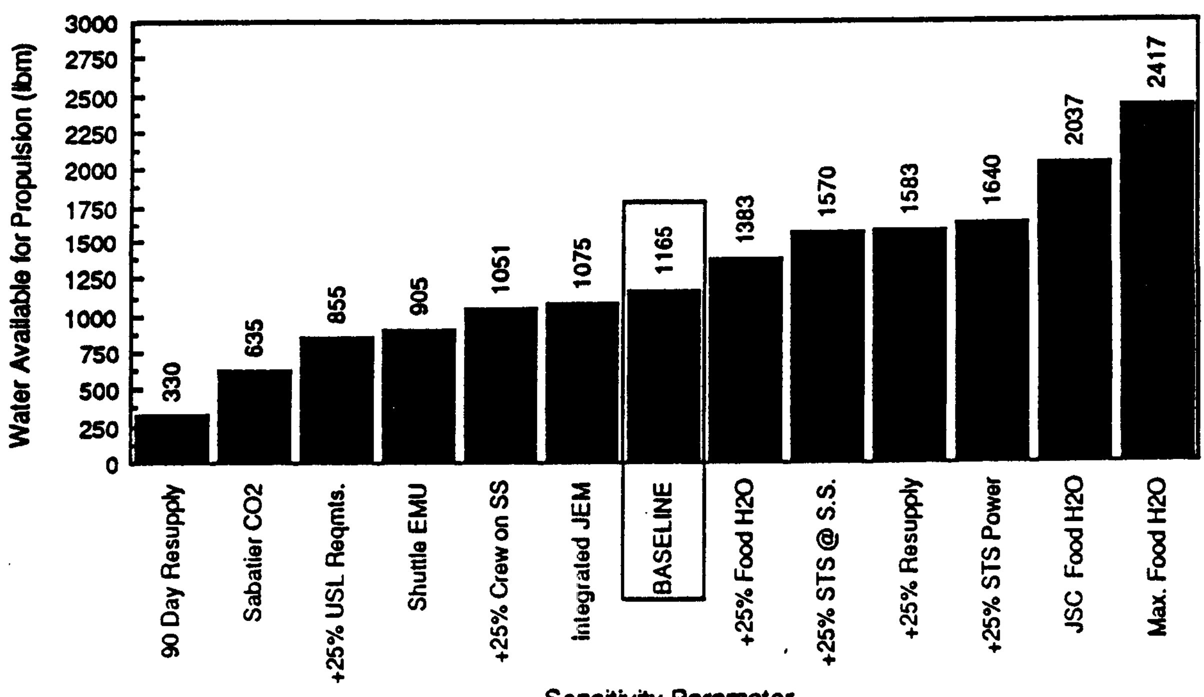

Figure 3.6-2 Water Sensitivity Analysis -- Absolute Scale

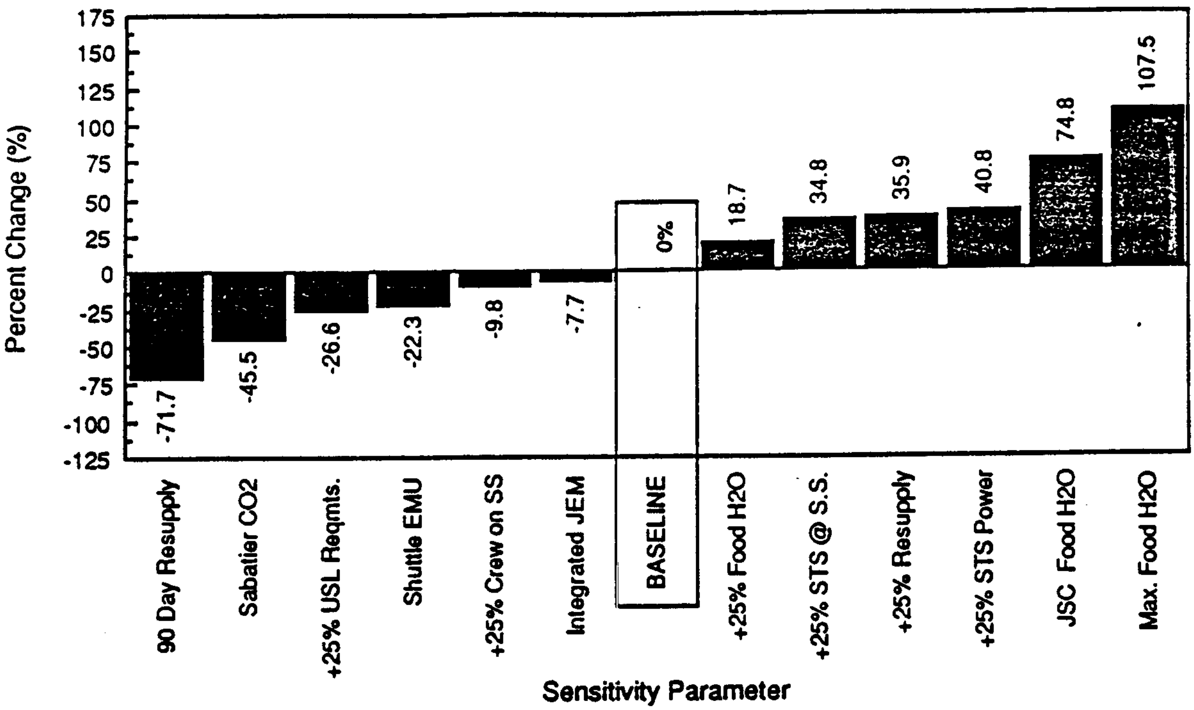

Figure 3.6-3 Water Sensitivity Analysis -- Percent Change from Baseline

large negative effect, decreasing the excess water by 72%. The water balance spreadsheets for each sensitivity parameter are presented in Appendix C of the "Fluid Management Systems Databook."

Increasing the water content of the food is an approach for increasing the total excess water at low cost and low technological risk. Increasing the food water content to the Johnson Space Center (JSC) baseline amount of 2.2 lbm/man-day[10], generates 2037 lbm total excess water per 90 days. Increasing the food water content to the maximum content of 2.68 lbms/man-day, as recommended by Al Boehm of Hamilton Standard[9], generates over 2400 lbm excess water. This "maximum" content is the maximum amount of water in a normal diet that is not wasted. An increase of the food water content would also make the food more palatable and simplify cooking procedures. Drawbacks associated with increased food water content are increased food volume and mass, and subsequently larger food storage devices. JSC indicated that the food water content baseline was to be changed from 1.1 to between 2.2 and 3.0 lbm/man-day, so the Hamilton-Standard number of 2.68 concurs with the JSC baseline.

3.6.1 Shuttle Orbiter Water Generation and Availability

The NSTS orbiter fuel cells generate ultrapure (pyrogen-free) water that is available for use on the Station. The amount of ultrapure water generated as a function of the NSTS fuel cell power level is shown in Figure 3.6-4[11]. This water is stored in four 165 lbm capacity metal bellows tanks at an operating pressure of 8-17 psi.[12] These tanks are used to store water for use in the fuel cell flash evaporater cooling system. The water available for Space Station use is equal to the amount of water generated by the fuel cells less the amount of water consumed by the astronauts aboard the Shuttle. This amounts to 1671 lbm for a 90 cycle for the reference configuration of 2 orbital visits, with 5 day visit durations, fuel cells powered to 10 kWe and four members aboard the Shuttle. Standard operating procedure while on orbit is for the fuel cell water to be vented to space; however, when docked to the Station the Space Station environmental contamination constraints preclude the venting of this water. The orbiter storage tanks are too small to store all the water generated during a typical stay at the Station, there-fore, to meet environmental requirements and to reduce propellant delivery costs, the excess water should be transferred to the Station.

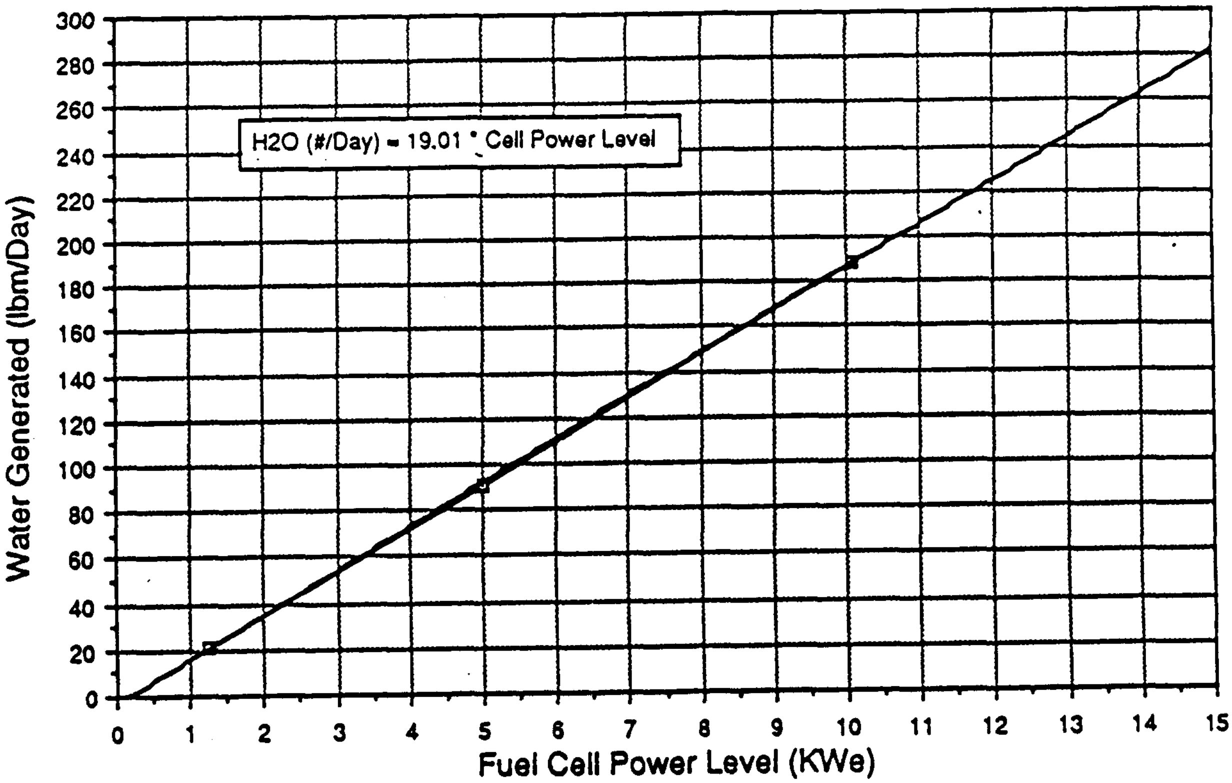

Figure 3.6-4 NSTS Fuel Cell Ultrapure Water Generation Rate

The water from the shuttle tanks is accessible from the contingency H_2O cross tie in the shuttle mid-deck. A simple flex hose connection between the mid-deck cross-tie and a quick disconnect (QD) located on the potable water line in the node to which the orbiter is docked has been proposed to eliminate permanent hardware. A small portable pump would be required to transfer the water from the shuttle to the Station due to the lower operating pressure in the tanks on the orbiter.

The orbiter waste water tank will also fill up during a typical mission. Each shuttle crew member generates about 7.46 lbm of waste water per day. This waste water is stored in a single metal bellows tank identical to the ultrapure tanks and is also periodically vented overboard. As with the ultrapure water, the Station venting constraints preclude the venting of the waste water to space, and the amount generated will be too large to store during a typical shuttle stay. No provision for waste fluid transfer from the shuttle to the Station ECLSS is anticipated, though, because of the safety concerns of pumping a contaminated fluid across interface connections. The best solution is to require the shuttle crew members to use the Station facilities for washing and urinating. Eighty percent of the waste water generated during a typical shuttle stay will be input into the Station ECLSS this way. Respiration and perspiration water will then be the only inputs into the shuttle waste tank.[13]

3.6.2 Propellant Water Requirements

Excess potable water is electrolyzed and used in the H_2/O_2 thrusters for Station altitude reboost. Thus the amount of potable water generated has an effect on the water storage and logistic resupply requirement. The amount of propellent required changes as a function of the atmospheric drag the Station encounters. The amount of upper-atmospheric drag is difficult to predict because the upper atmosphere expands and contracts in concert with the solar wind, while the solar wind is a function of the solar activity (sun spots, flares, etc.), and the season (the position of the Earth in its elliptical

orbit). This expansion and contraction can change the density of the upper-atmo- sphere by many orders of magnitude in a short period of time. Therefore, because of the uncertainties in the amount of drag, there is uncertainty in the amount of drag-makeup propellent required. Two cases, a "nominal" atmosphere model and a "+2 sigma" atmospheric model[14], have been used to develop propellant requirements for Space Station reboost. The +2 sigma model can be thought of as an upper bound to the average amount of drag the station will encounter.

The amount of water required for reboost must be known in order to size the on board tankage. Figures 3.6-5 and 3.6-6 show the variation in reboost propellant between the nominal and +2 sigma cases during the two years prior to IOC and the first year after IOC. Two scenarios have been developed for resupply, one resupplying at 45 day intervals, the other at 90 day intervals. NASA requires storage of 45 days worth of contingency propellent in case of a missed resupply. As can be seen in the two figures the worst case is the 90 day resupply period (giving a 135 day storage requirement) over the dates of 1-1-95 through 4-15-95. During this 135 day period the propellant requirement is about 5000 lbs. The USL requirement can be added to this and the water generated by the ECLS system subtracted to give the amount of water which must be stored. The USL requirement is 1240 lbm/90 days. Only the 90 day requirement is added to the propulsion requirement because it is assumed that if a resupply period is missed the Station will go into a slow down mode to save resources, and most, if not all, experiment activity will cease. As a worst case analysis the lower water producing CO_2 reduction process was chosen to size the system. The Sabatier process generates approximately 1457 lbm of water over 135 days. These parameters indicate a total storage requirement of 4783 lbm.

3.6.3 Logistics Elements Water Resupply

Water may be supplied from the ground in order to supplement the amount of water generated by the ECLSS system and scavenged from the shuttle. Water is required for propulsion and experiment use. The impact of the Space Station elements and environment on the amount of water required from logistic resupply was studied. The parameters included the following: the Bosch and Sabatier CO_2 reduction processes, 45 day and 90 day shuttle resupply frequency, nominal and +2 sigma atmosphere models. The food water content was assumed to be 2.68 lbm/man-day. The baseline numbers were used for the rest of the parameters. The results can be seen in Figures 3.6-7 through 3.6-10. These figures show the amount of water which must be launched into orbit via the shuttle during a typical three year period. Figure 3.6-7 shows a scenario in which no logistically supplied water is required. In the case of a 45 day resupply period, Bosch or Sabatier reduction, and a nominal atmosphere, enough excess water is generated and scavenged to provide the total amount required for propulsion, thus no resupply water is required and more productive use can be made of the NSTS payload. In Figure 3.6-10 the opposite is shown. If a 90 day resupply period and the Sabatier CO_2 reduction process is used during a +2 sigma atmosphere, then over 1200 lbm of water will have to be launched to the Space Station on each resupply flight. This issue will not be resolved until a more accurate atmosphere model is developed and the Space Station configuration is finalized.

3.6.4 On Orbit Water Resupply System Configurations

As a worst case analysis a logistic resupply requirement was assumed to exist. JSC's Architectual Control Document shows that the PLC will have ECLSS potable water and nitrogen lines running through the module[15]. Therefore it is proposed that the resupply water be sent directly into the potable water line from the resupply tank. Preliminary resupply and transfer systems are shown in Figures 3.6-11 through 3.6-16. Water transfer is conducted through the use of a pressurized diaphragm tank. Diaphragm tank technology is well-developed and would be inexpensive to develop for use in a man-rated system. The main technology gap is controlling the contamination of potable water by the diaphragm material. However, the bening nature of the fluid may reduce

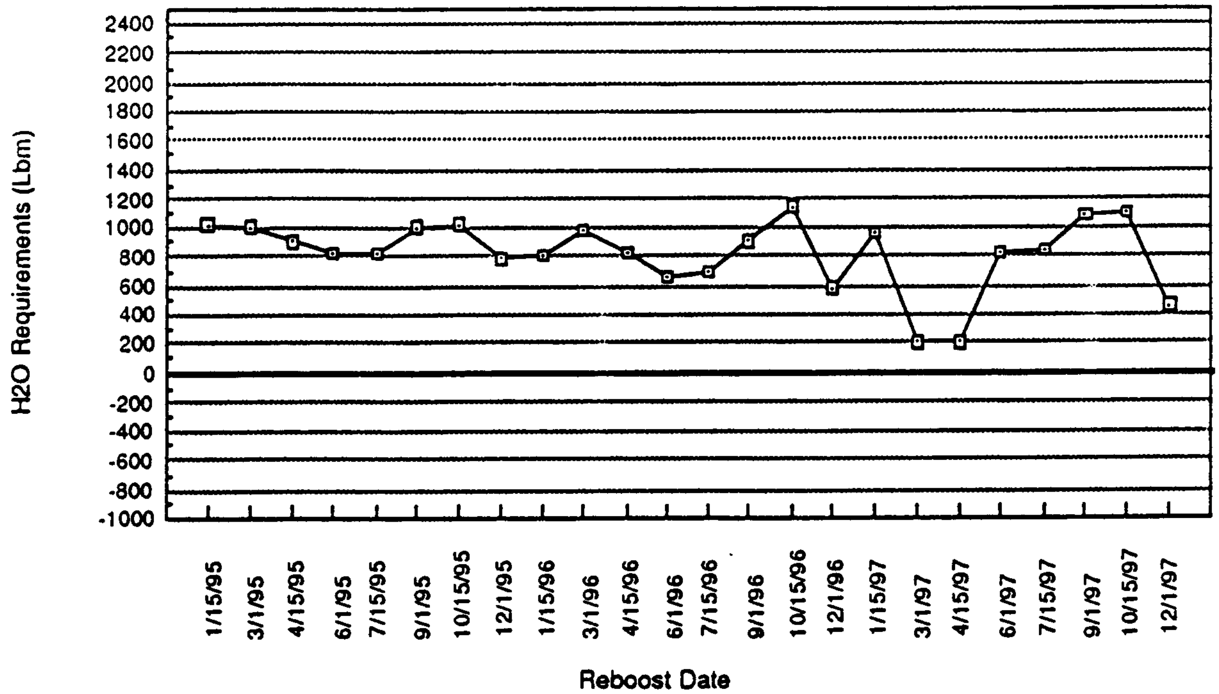

Figure 3.6-5 Typical Reboost Requirements for Nominal Solar Activity

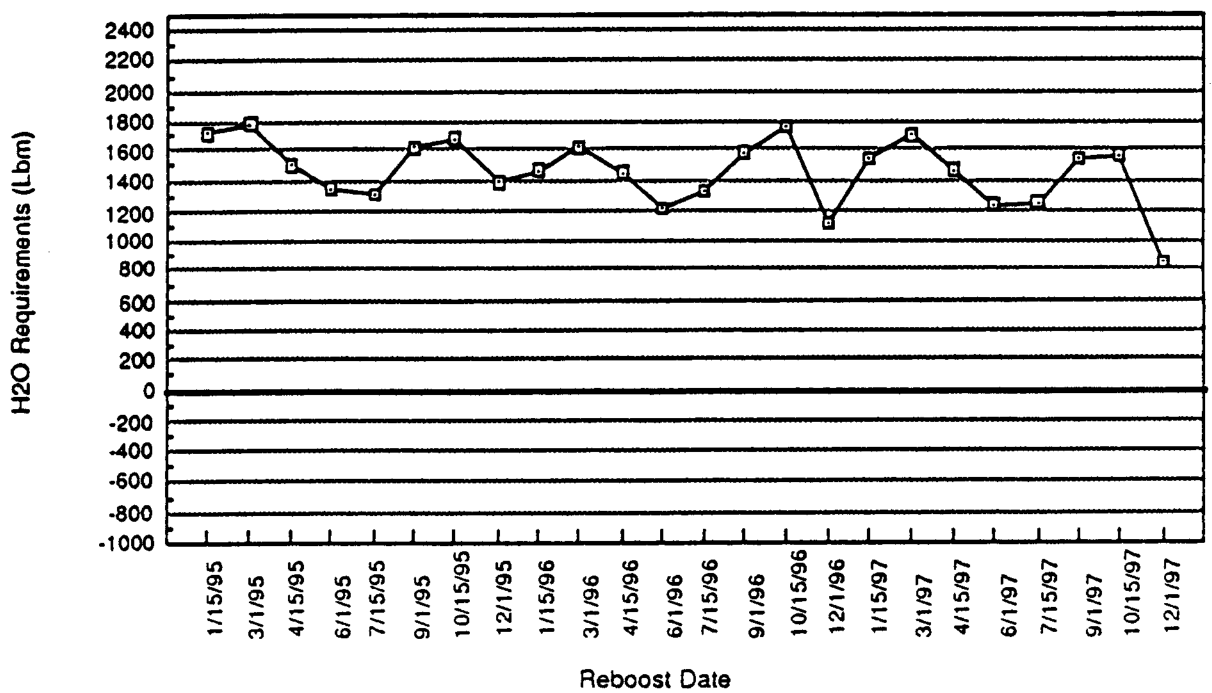

Figure 3.6-6 Typical Reboost Requirements for +2 Sigma Solar Activity

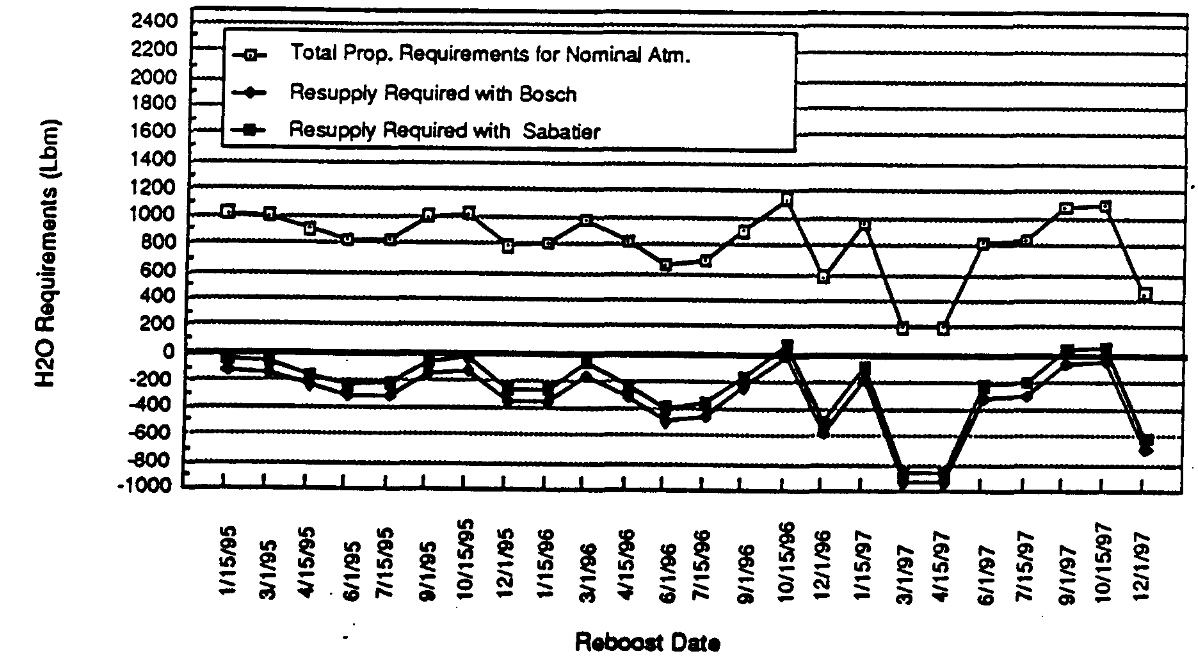

Figure 3.6-7 Typical Water Resupply Requirement for Nominal Solar Activity with 45 Day Resupply Cycle

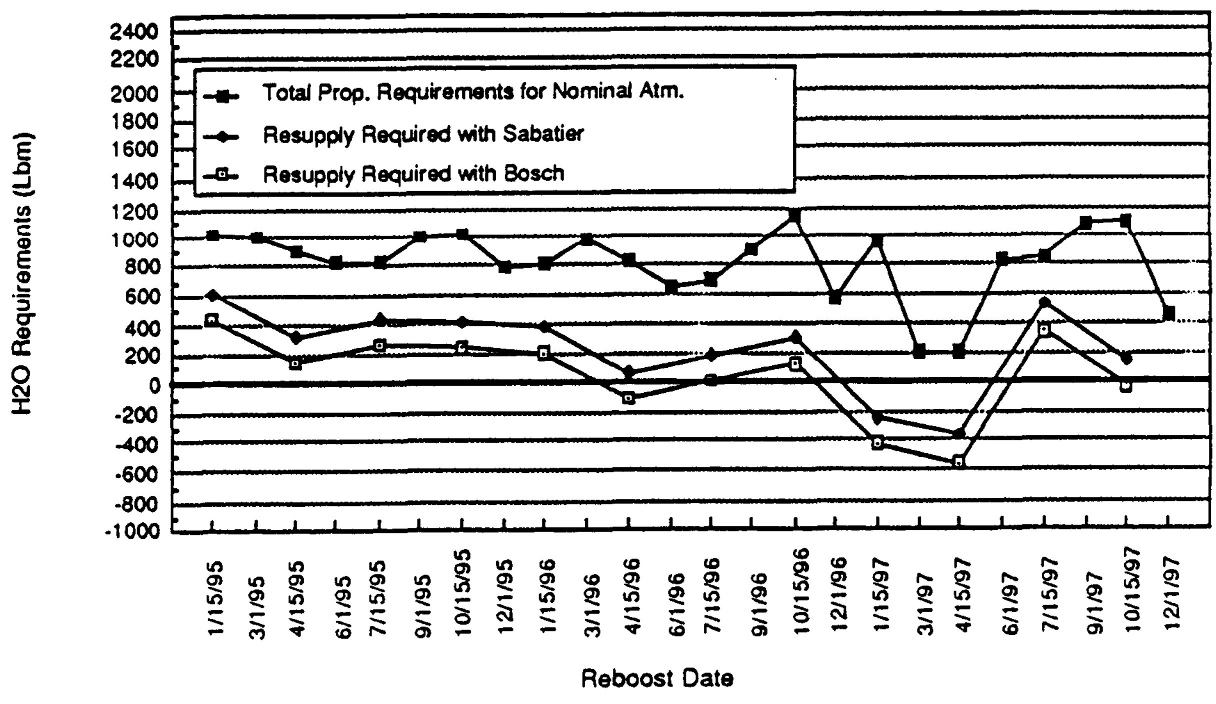

Figure 3.6-8 Typical Water Resupply Requirement for Nominal Solar Activity with 90 Day Resupply Cycle

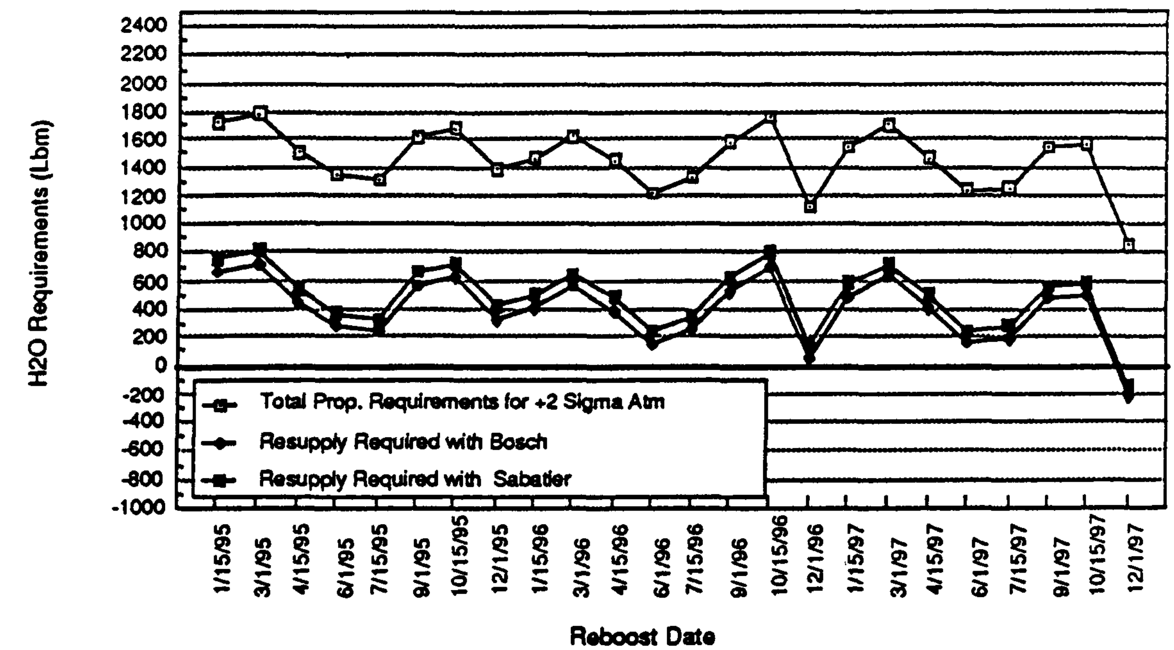

Figure 3.6-9 Typical Water Resupply Requirement for +2 Sigma Solar Activity with 45 Day Resupply Cycle

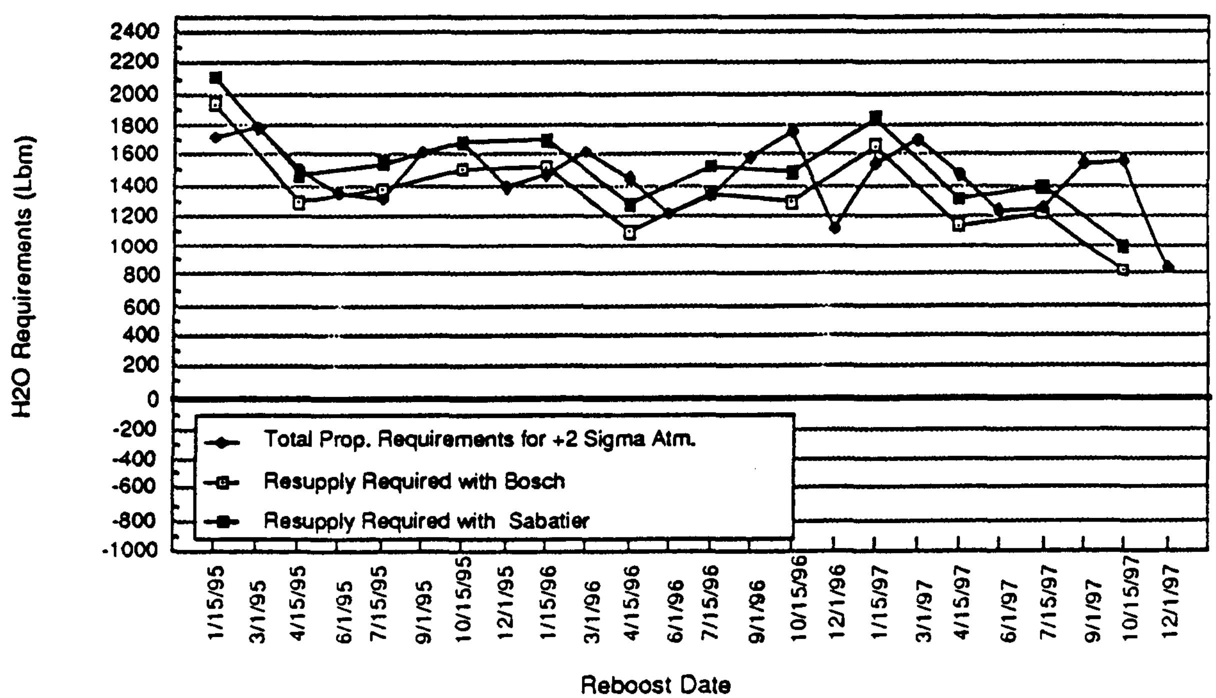

Figure 3.6-10 Typical Water Resupply Requirement for +2 Sigma Solar Activity with 90 Day Resupply Cycle

potential material problems found with hydrazine diaphragm tanks. Figures 3.6-11 and 3.6-12 show a proposed water resupply rack where separate pressurant GN_2 bottles are connected to the diaphragm tank. The bottles operate in either blowdown (Option 1) or regulated (Option 2) mode. Figure 3.6-13 shows the use of the INS to pressurize the tank via flex lines and QD's (Option 3). Option 4 uses a small portable pump between the PLC and potable tank with a gas bottle providing the necessary net positive suction head (NPSH) for the pump, as shown in Figure 3.6-14. Figure 3.6-15 shows a pressurized ullage in the water tank for providing the NPSH for pumped transfer (Option 5). Finally as shown in Figure 3.6-16, pressurizing the tank ullage to a high enough pressure will force the fluid into the water lines in blowdown operation (Option 6).

Options 1 and 2 incur the hardware cost and weight problems associated with the pressurant bottles. In Option 3, the flex line and valve assemblies that attatch to the N_2 and water lines would be kept on the Station, decreasing launch weight. No pressurized ullage would be required, allowing for a greater amount of water to be loaded into the tank. Option 4 has the weight problems and hardware costs of both pressurant bottles and a pump, but the pump decreases the pressurant bottle's pressure. The advantage of operating at a lower pressure is a decrease of the required wall thickness and therefore of the weight of the tanks. The pump could be common with the pump used in transferring the shuttle fuel cell water to the Station potable lines. Option 5 has the advantage of requiring only one connection and one flex-line/valve assembly but incurs penalties due to both the larger volume associated with a pressurized ullage and the hardware cost of a pump. From the hardware point of view, Option 6 is the least expensive method, but the ullage required to pressurize the tank decreases the volume available for water and increases the weight of the tank, which increase launch costs. From this simple analysis, option 3 would be the best choice. It uses the resources provided by the Station and components with current technology to facilitate fluid transfer, and incurs the lowest launch costs and lightest tank weight while providing the greatest volume of water per mass of tankage.

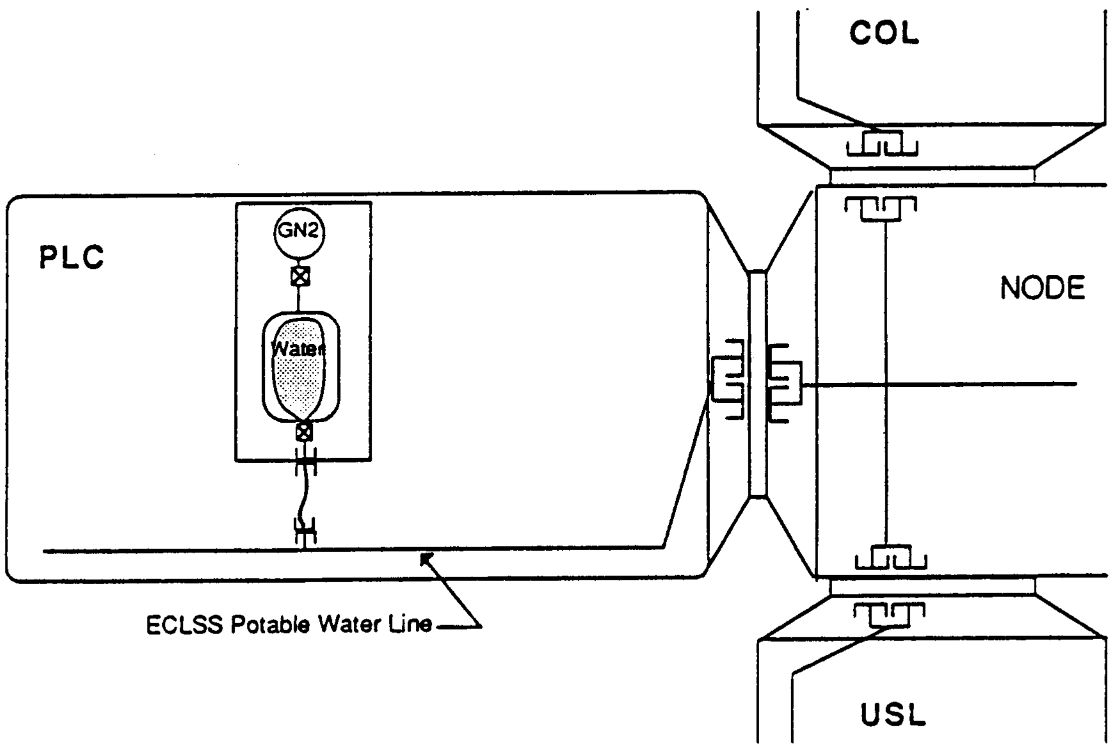

Figure 3.6-11 Option 1 - Water Resupply Tank with Separate Blowdown Pressurant Tank

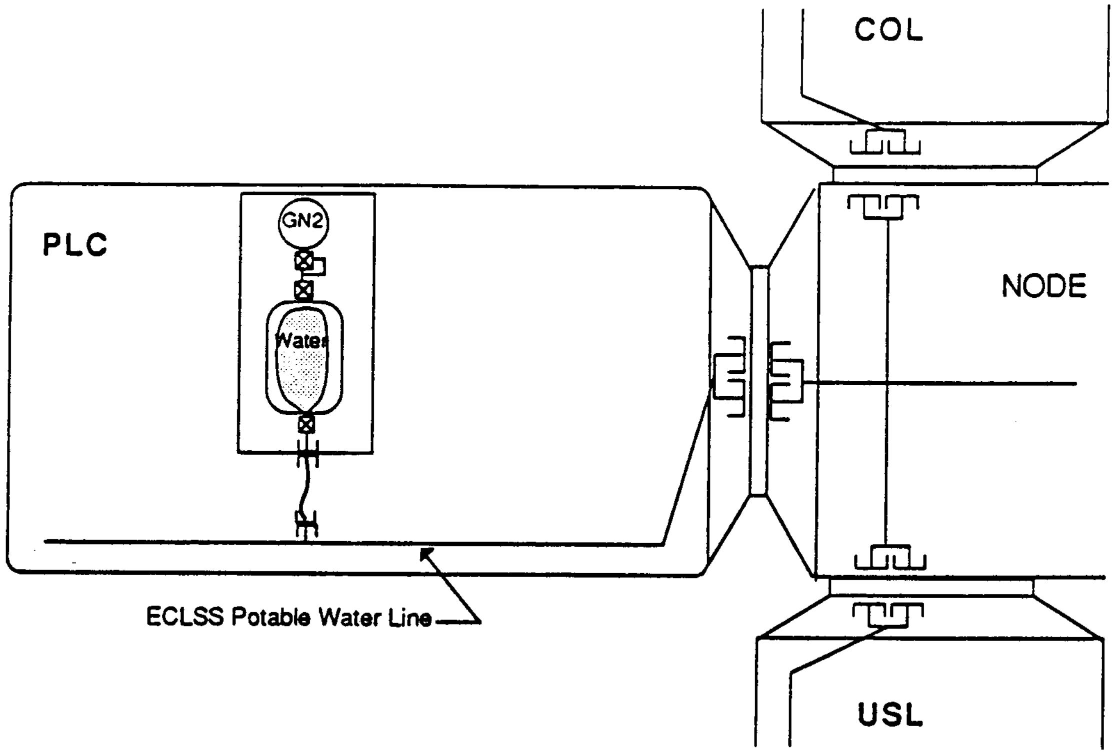

Figure 3.6-12 Option 2 - Water Resupply Tank with Separate Regulated Pressurant Tank

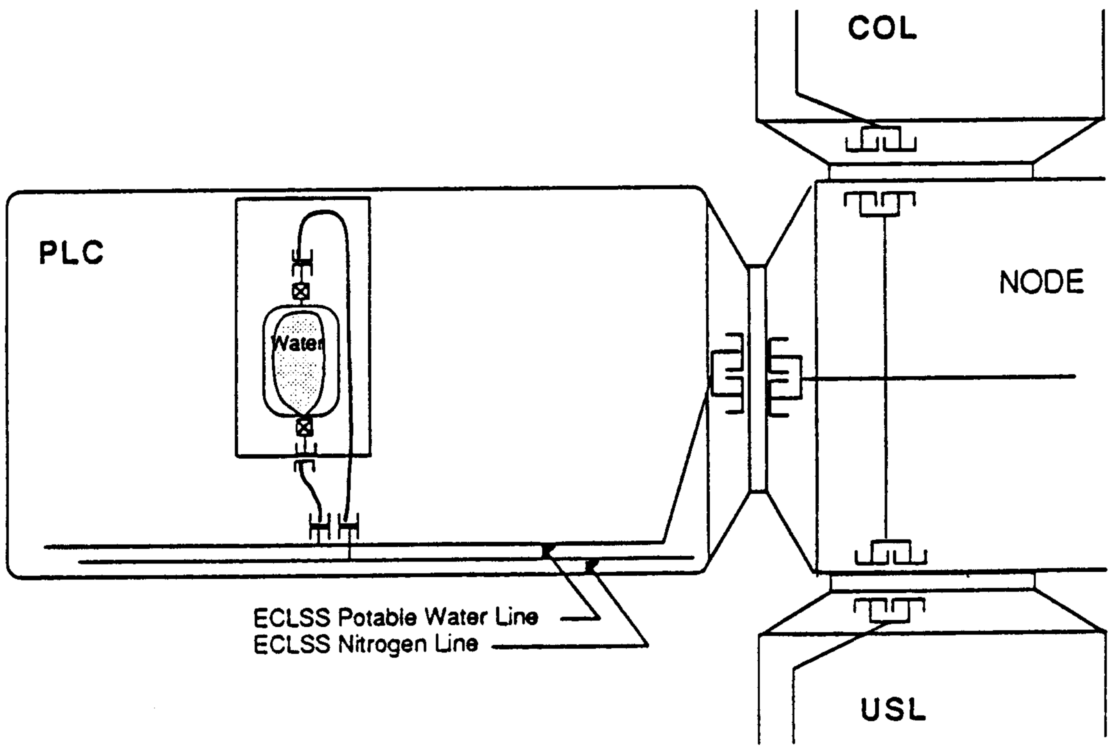

Figure 3.6-13 Option 3 - Water Resupply Tank with Integrated Nitrogen System Pressurization

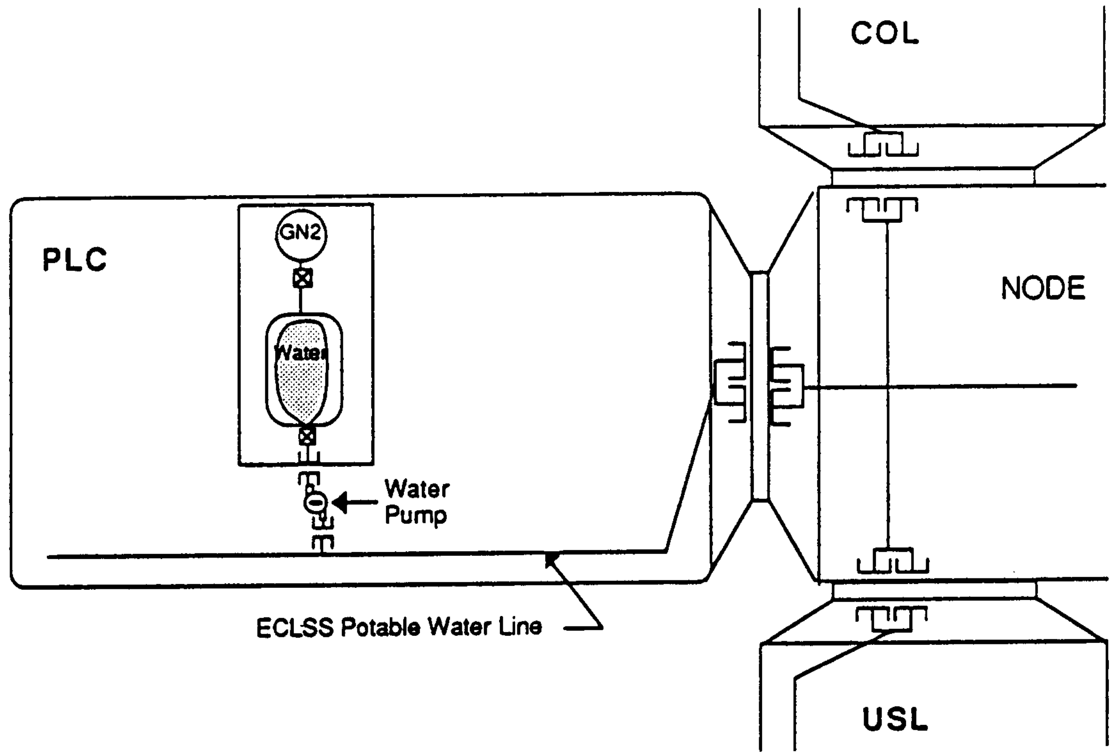

Figure 3.6-14 Option 4 - Water Resupply Tank with Separate Regulated Pressurant Tank and Portable Pump

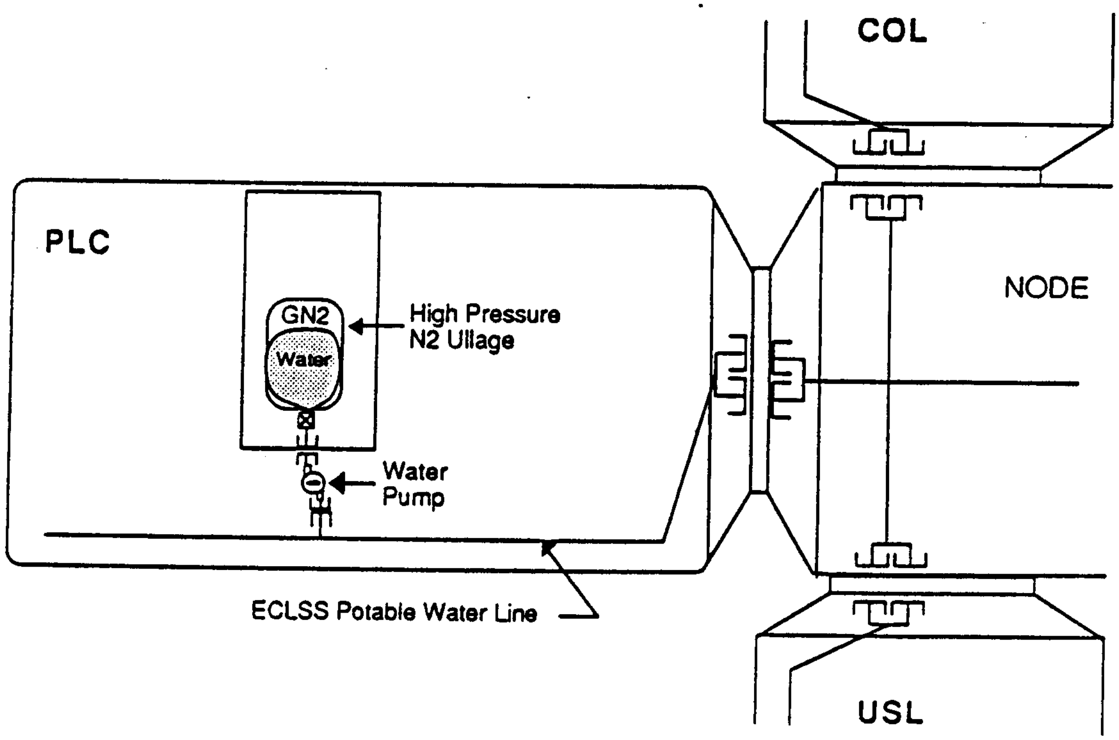

Figure 3.6-15 Option 5 - Water Resupply Tank with Pressurized Ullage and Portable Pump

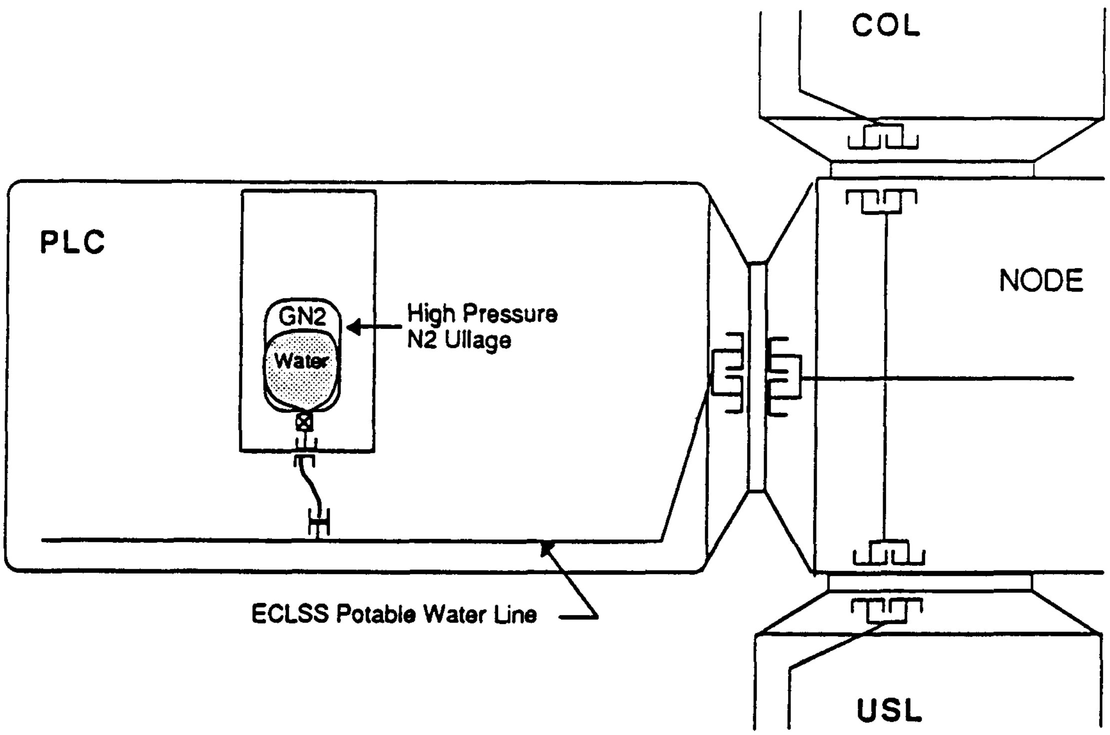

Figure 3.6-16 Option 6 - Water Resupply Tank with Blowdown from Pressurized Ullage

3.6-5 On Stage Water Storage and Distribution

The IWS Space Station distribution lines must conform to the requirements set out in the various NASA documents. These requirements include the following:

1) Water distribution plumbing consists of lines, valves, and QD's to facilitate the integration and distribution of all water to the various subsystem components and to and/or from the various water users (JSC 30262).
2) The collection, processing, and dispensing of water (with exception of laboratory waste water) to meet evolving Space Station crew and other potential needs shall be accommodated (SS-SRD-0001, Sec. 3).
3) The capability to disinfect/sanitize the water system shall be provided (Space Station Man-System Integration Standards, NASA-STD-3000).
4) Potable water shall be provided by closed loop, with capability of NSTS resupply (USL CEI (SS-SPEC-002)).
5) Processed water shall be supplied to accommodate PMMS resupply (USL CEI(SS-SPEC-002)).
6) Processed water shall be available for immediate use (USL CEI (SS-SPEC-002)) and (HAB CEI (SS-SPEC-0100)).
7) The system shall be designed to preclude inadvertent contamination of the processed water (USL CEI (SS-SPEC-002)) and (HAB CEI (SS-SPEC-0100)).
8) Water used to remove toxic or corrosive chemicals or other contaminants that would be hazardous to the crew shall be isolated from all other hygiene water sources unless it can be proven that the water recovery loop is able to remove the substance(s) from the water (HAB CEI (SS-SPEC-0100)).

Storage for these and other water requirements has been proposed to be in the form of potable water, with transfer taking place via the ECLSS potable water lines. The potable water lines run throughout each module and node, including the international modules. This scenario facilitates transferring water to the users without an additional requirement for dedicated lines. A connection is made to the ECLSS system racks in the HAB and USL modules to provide the input of ECLSS excess potable water generated into the node water storage. Thus non-experiment waste water is processed by the ECLSS system and put back into the system. Provisions are made for the transfer of make-up water from a PLC tank and of scavenged ultrapure water from the orbiter fuel-cells. There is a connection with the USL Process Material Management System (PMMS) to provide potable water to the experiments. Water is supplied to the pure side of the PMMS recycling system and isolated from the potable water loop to preclude contamination in the ECLS system. This eliminates both the need for a make-break connection and the requirement for crew intervention for fluid transfer from the potable water lines to the experiment storage tank.

3.6.5.1 <u>On-Board Water Storage Concepts</u> - The Space Station water storage volume is divided among four identical water storage tanks. Each of the four tanks is located in one of the four nodes on the Space Station, as shown in Figure 3.6-17. The Gamma Ray Observatory propellant tanks are good candidates for use as water storage tanks. They will be space qualified by 1992, are diaphragm tanks for ease of fluid transfer, and are sized such that one tank will fit into a standard USL double rack. Distributing one tank into each node will increase safety, and placing them in standard racks will allow for modularity. Four tanks will provide a capacity of 5288 lbm, allowing a 10% margin for the worst case studied.

The water tanks are pressurized with N_2 supplied by the Integrated Nitrogen System (INS) as shown in Figure 3.6-18. Waste N_2 from the tanks is vented to the modules as leakage and air lock loss makeup. The vent rates are small (17 lbm/90 days) and the gas is pure and uncontaminated, thus venting directly from the diaphragm tank to the module will cause no safety problem. The station will leak about 4 lbm of N_2 per day and the ECLSS system is required to makeup this air loss. Using the water pressurization N_2 for cabin air makeup reduces resupply requirements by using the same gas twice.

Figure 3.6-19 shows the water stored in a pallet outside of the modules. This storage option may provide an advantage as volume is limited commodity on the Space Station, and four double racks would be freed for experiment use. Tank change out via a pallet in the ULC or PLC will be facilitated using the Station or shuttle Remote Manipulator System. There are some problems with outside strorage, including: exposure of the water pallet to meteorite damage could cause catastrophic loss of reboost propellant; thermal conditioning of the water would be required; the cost of EVA repairs in the event of a water system failure is much greater than for IVA repairs; and the Station pressure shell would have to be perforated for the water line to pass through.

3.6.5.2 <u>On-Board Water Distribution</u> - An important architectural decision to be made is that of a circulating versus non-circulating distribution system. A major concern is that microbial growth and biofilm formation may occur in locations where water does not flow. Data which conflicts with these concerns, such as that from shuttle experience, shows that high quality water with a residual halogen biocide does not require continuous circulation to prevent microbial growth.

The most promising approach for preventing growth without circulation is the one used on Shuttle, i.e. maintaining a residual biocide (iodine) concentration. Provision of circulation and biocide monitoring capability for the storage tanks may be necessary to ensure that proper biocide

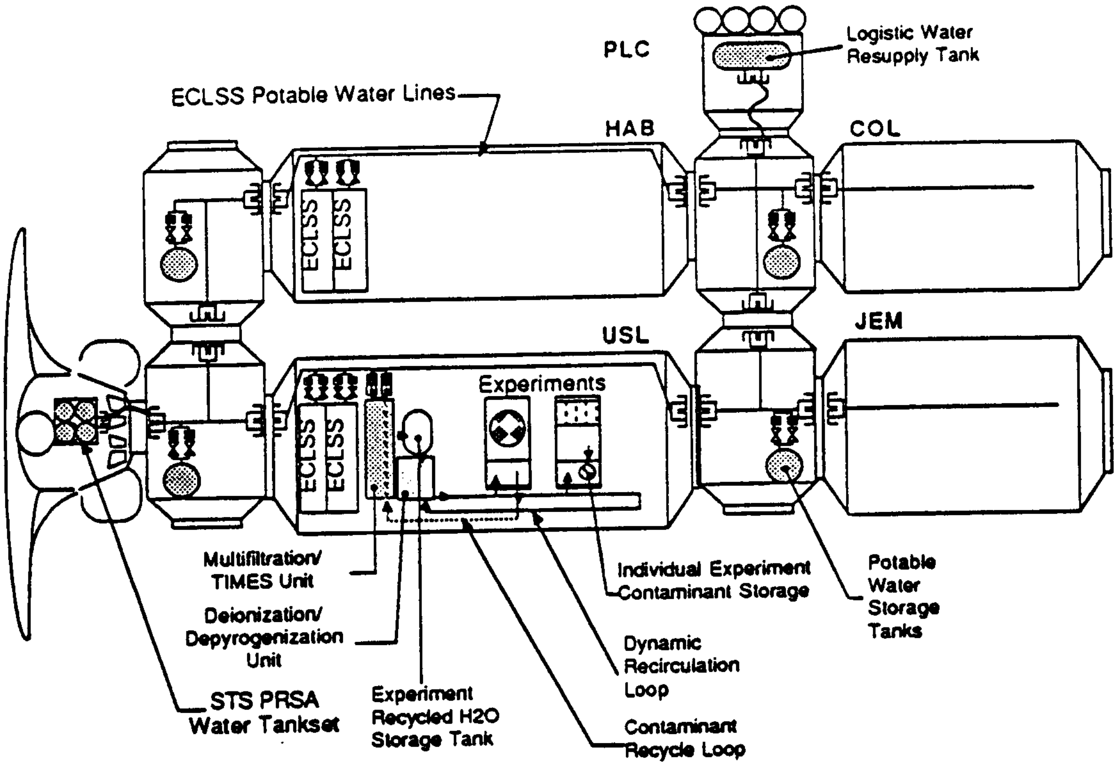

Figure 3.6-17 Potable Water Storage in Nodes

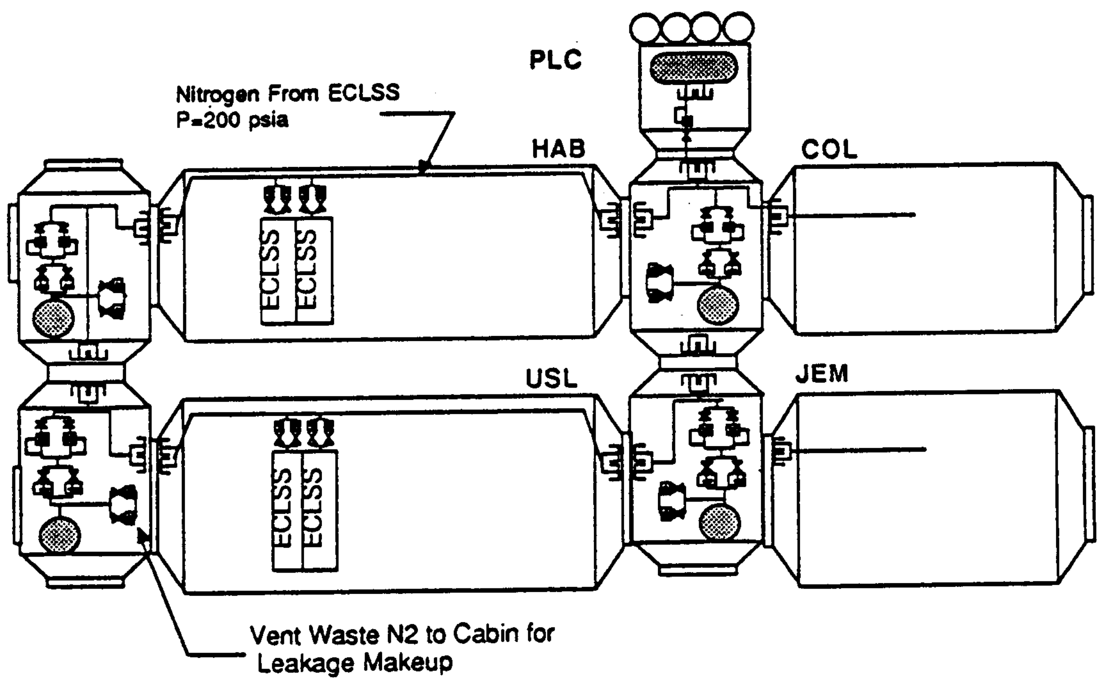

Figure 3.6-18 Integrated Nitrogen System Pressurization of Potable Water Storage in Nodes

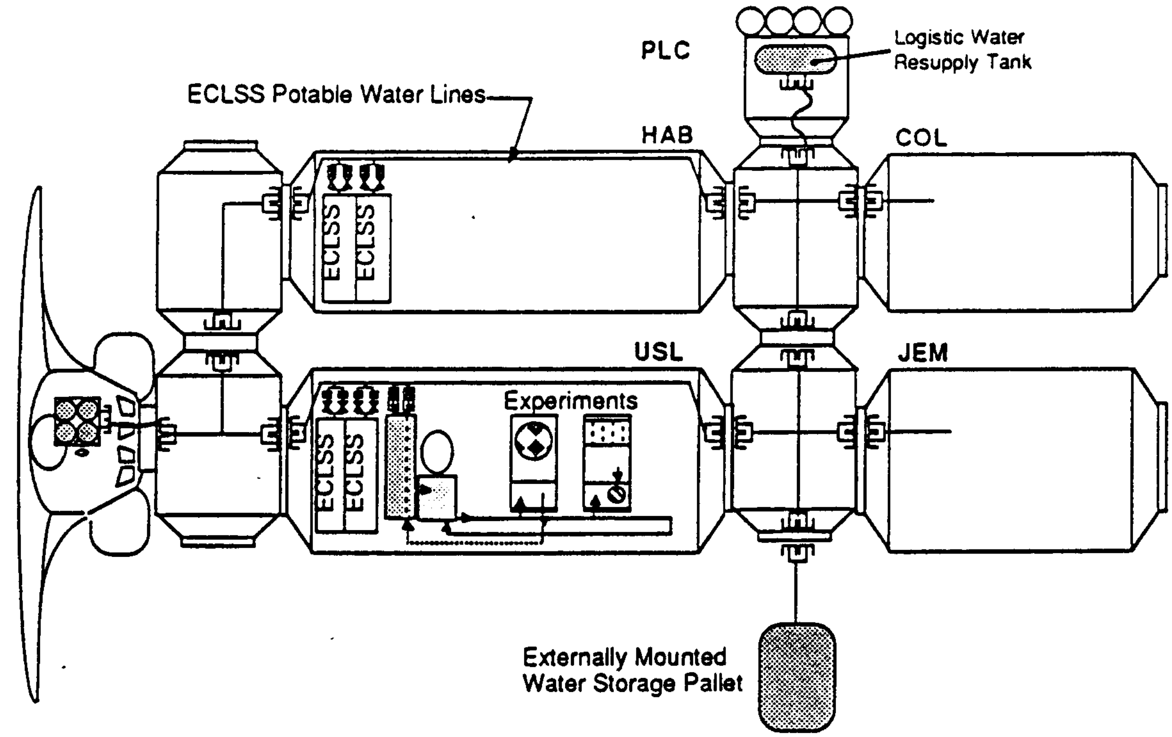

Figure 3.6-19 Water Storage Outside of the Modules

levels are constantly maintained. Microbial check valves (MCV's, iodinated resins) may also be required in-line in the water distribution piping to ensure maintenance of residual biocide, and to prevent migration of contamination. At a minimum, MCV's should be installed at all interfaces of the integrated water system to minimize the possibility of microbial back-contamination.

The final decision on circulating versus non-circulating distribution must be deferred until such time that sufficient long term tests with water, biocide, and piping materials can be completed.

Since the potential may exist for microbial contamination of the water distribution system, it is recommended that the system be designed to minimize the impact of inadvertent microbial contamination, and to provide the capability for microbial decontamination. Isolation valves should be included to provide the capability of isolating each module, as well as the piping runs in individual standoffs. Pressure and flow sensors provided in the piping for each standoff would aid in isolation of problems. Connections to individual racks should include an isolation feature. Connections should also be provided in each module endcone to accommodate orbital support equipment for decontamination. Several options have been identified for both chemical and microbial decontamination of water piping. These options are discussed in Appendix B of the "Fluid Management Systems Databook."[6]

The baseline method of supplying experiment water to the JEM is to use Portable Pressure Vessels (PPV) launched into orbit in the Japanese Experimental Logistics Module (ELM). JEM and COL could be integrated into the IWS by supplying potable water for use in their experiments, and storing the waste water in Portable Waste Vessels (PWV). An ECLSS potable water line already runs into the JEM and COL. Therefore, disconnects and flex lines which tap off of the ECLSS line could be used to distribute the required amount of water. A dedicated waste water line from the JEM to the USL is too dangerous due to possible leaks and subsequent contamination of living spaces. One method of recovering the JEM or COL waste water is to hand carry the PWV's to the USL for proscessing by the WMS. The PWV would be a bladder tank and fluid transfer would be conducted by pressurizing the tank with the INS. The bladders could be changed out and disposed of in case of gross contamination, and the tank itself reused.

3.6.6 RECOMMENDATIONS

The decision on the final disign configuration cannot be made until further decisions are made regarding such things as the amount of water in the food, the frequency of orbiter visits, and the amount of circulation required. A concept has been presented which stores water in diaphragm tanks in the nodes and uses a high food water content (2.2-2.68 lbm/man-day). This concept would provide the necessary water for any contingency situation.

3.7 INTEGRATED NITROGEN SYSTEM

Nitrogen is an extremely important fluid requirement of the Space Station. Nitrogen is the primary constituent of air for life support, and is necessary for atmospheric control operations. Nitrogen is also used for potable water pressurization, experiments, and emergency life support operations such as safe-haven, hyperbaric airlock pressurization and module repressurization. Liquid nitrogen is used aboard the USL for cooling in the experiments. Eventually, nitrogen will be needed for use by various vehicles, platforms and servicing facilities in support of the Space Station at post-IOC.

Commonality and integration issues were evaluated during study of the integrated nitrogen system. Commonality and integration are very important factors in reducing the quantity of hardware used and its associated costs. Such a system will be capable of delivering nitrogen to any and all users on demand and at the required fluid conditions. The optimal system will be developed by reducing hardware development, maintenance and resupply costs, and by enhancing growth potential and eliminating safety concerns.

The INS consists of a supply subsystem, a storage subsystem and a distribution subsystem. Each of these subsystems are described and illustrated in the following paragraphs. The integrated nitrogen system performs the functions of resupply, transfer, storage, fluid conditioning, and the control and monitoring of supply and delivery conditions. The Reference INS is illustrated in Figure 3.7-1. The supply subsystem must be resupplied every resupply period, or every 90 days[4], in order to assure that the appropriate amount of nitrogen will be stored and available for normal use. Fluid storage and delivery conditions are continually monitored so that nitrogen is maintained and delivered at the proper temperatures and pressures and storage levels are known for scheduling and resupply purposes. Hardware commonality is designed into the INS by developing the subsystems with the same hardware types.

3.7.1 Supply Subsystem Definition

The INS supply subsystem consists of the tankage, structural, mounting, conditioning, thermal control, transfer, and control and monitoring hardware necessary for delivery of the nitrogen to the distribution subsystem and then to the user interfaces. The supply subsystem hardware is delivered by the Logistics Elements as a fluids pallet encompassing the above hardware. Operational flexibility in the supply subsystem is enhanced by incorporating conditioning hardware specific to a given resupply concept within the subsystem pallet, such as heaters, pumps, compressors, or any other components necessary to condition the nitrogen in the pressure vessels. By including items on the supply pallets that require periodic maintenance, on-orbit maintenance can be eliminated. The INS supply subsystem pallet is primarily responsible for performing the dual function of resupply and storage of nitrogen for normal every day operations. It also performs a secondary function of resupplying nitrogen for transfer to the storage subsystem. The supply subsystem pallet configuration allows for the incorporation of additional pressure vessels when the normal user nitrogen requirements change or grow over the life of the Space Station[16, 17].

Two redundant interface locations are allocated for supply subsystem pallets. These interfaces are optimally located to simplify on-orbit resupply, EVA maintenance and nitrogen delivery operations. A single fluids pallet resupplied every 90 days will occupy one of the interface locations. The second interface location is available for docking of a resupply pallet for a subsequent resupply period, allowing resupply pallets to overlap while nitrogen from the existing fluids pallet is still being consumed during a subsequent resupply period. An overlap period may extend up to many days while the NSTS shuttle remains docked to the Station. Under these conditions, the first pallet would not be deorbited until the next resupply period. In addition to allowing for resupply overlap, the second interface location may allow for docking of a resupply

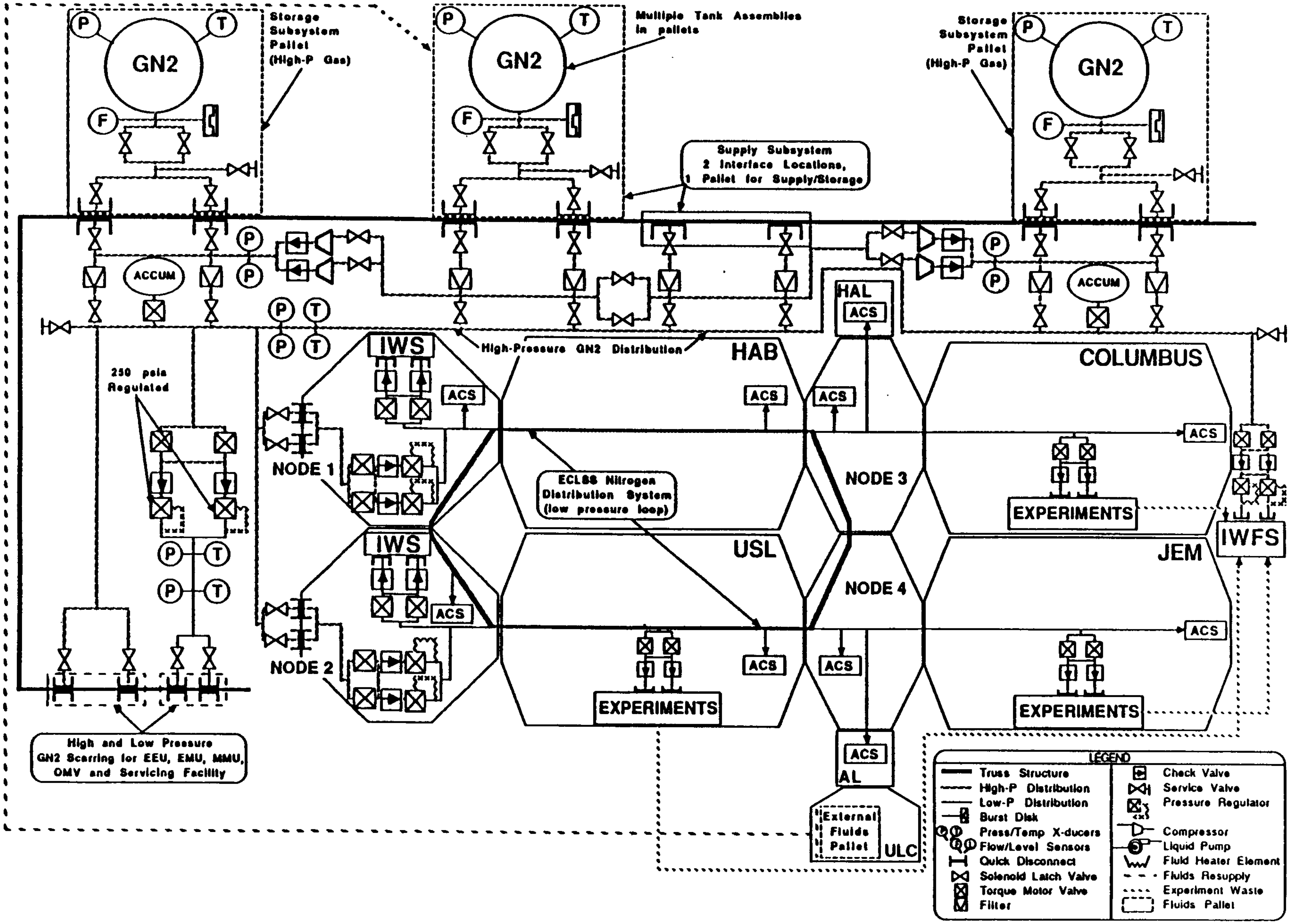

Figure 3.7-1 Integrated Nitrogen System Reference Configuration

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pallet used strictly to transfer nitrogen to the storage subsystem.

3.7.2 Storage Subsystem Definition

The INS storage subsystem will provide sufficient storage to satisfy emergency ECLSS and contingency requirements[18] for gaseous nitrogen. The storage subsystem is comprised of a permanent, on-board gaseous nitrogen storage pallet system similar in nature to that of a supply subsystem pallet, except that it is permanently affixed to the SS truss structure. The storage subsystem pressure vessels are resupplied from the supply subsystem either with the use of compressors or through a blowdown transfer process. A high pressure gaseous storage subsystem concept was selected on the basis of its simplicity in design and its capability for long-term storage since it is required for emergency use only. The option for a cryogenic storage subsystem is eliminated since such a system will require excessive monitoring and conditioning. The gaseous system has a high potential for blowdown resupply without the use of additional transfer or conditioning hardware. The storage subsystem is located external to the pressurized modules, like the supply subsystem, and is required to have two independent isolated pressurized volumes[18], each with the capability to supply the full amount of emergency and contingency nitrogen. This is required so that in the event that one pressurized volume is lost, another will be available immediately.

The storage subsystem nitrogen requirements, as mentioned before, are established for emergency situations such as repressurization of a module, hyperbaric airlock pressurization and contingency use when a resupply cycle is skipped. Similar to the supply subsystem flexibility, the storage subsystem pallet configuration will allow for the incorporation of additional pressure vessels should the emergency nitrogen requirements ever change or grow, or the operational requirements of the storage subsystem ever deviate.

3.7.3 Distribution Subsystem Definition

The INS distribution subsystem will deliver nitrogen from the INS supply subsystem interface to user interfaces at required temperatures and pressures. It delivers nitrogen that is blown down or compressed at a higher pressure and then regulated down to the final delivery pressure. In-line nitrogen delivery or transfer compressors, if required, will become an integral part of the INS distribution subsystem. Certain INS configuration candidates require compressors for delivery and/or transfer.

The INS distribution subsystem consists of the plumbing, connectors, mounting, conditioning, thermal control, transfer, and control and monitoring hardware necessary for nitrogen distribution to the user interfaces. This system is comprised of the valves, filters, disconnects, check valves, regulators, etc. to direct and control the distribution of nitrogen to the desired interfaces. This hardware includes any compressors necessary for nitrogen delivery to users or for repressurization of the storage subsystem. The plumbing consists of both high and low pressure lines. The high pressure gaseous lines are mounted external to the pressurized portion of the station and located along the truss structure. These lines are integrated with the supply and storage subsystems at their interfaces and at the user interfaces. Low pressure distribution lines run internal to the pressurized portions of the SS and interface the ECLSS distribution subsystem. The ECLSS distribution subsystem routes nitrogen through the nodes surrounding the USL and HAB modules (Nodes 1 and 2) and through the modules themselves from the ECLSS racks. The ECLSS racks are located in both the USL and HAB modules, comprising redundant systems. The ECLSS distribution subsystem is interfaced by the INS distribution subsystem at Nodes 3 and 4 (between the US and international modules) by the fully integrated systems to further distribute nitrogen to the international modules and to the USL experiments. The INS distribution subsystem is also scarred on the truss structure for eventual high and low pressure use by Post-IOC EVA systems and for future growth.

3.7.4 Integrated Nitrogen System User Fluid Requirements

The nitrogen user fluid requirements were established by compiling the best data possible from Space Station documents, contractor data, and Martin Marietta databooks regarding the required nitrogen user interfaces. Table 3.7-1 lists the nitrogen quantities that must be supplied, or available in the case of the storage subsystem, over any 90 day resupply period. Note that the last three figures represent the fluid quantities that must be available on board for potential emergency and contingency use and not quantities that are readily used over each resupply period. Similarly, Table 3.7-2 lists the fluid storage requirements per 90 day resupply period for the supply and storage subsystems.

3.7.5 Integrated Nitrogen System Assessment and Analysis

3.7.5.1 Integrated Nitrogen System Resupply/Storage Techniques - Essentially, three methods or techniques by which nitrogen will be resupplied and stored were defined. Resupply/storage concepts which allow the nitrogen resupply to be brought up as a high pressure gas (supercritical fluid) and as a cryogenic supercritical fluid have been defined on the subsystem level (supply subsystem) and were incorporated into overall integrated system configurations. In addition, a subcritical liquid resupply/storage concept for the supply subsystem was looked at as a third concept for the Integrated Nitrogen System Assessment and Analysis Tasks and likewise integrated into the storage and distribution subsystems. The comparison of high pressure gas and cryogenic supercritical resupply/storage techniques will be the primary focus of attention in this assessment. No mention has been made for a dedicated nitrogen supply or distribution system, however one configuration of note for gaseous users has been developed and an assessment was made. A dedicated LN_2 system is discussed in Section 3.7.7. The following is a list of the nitrogen resupply/storage concepts (supply subsystems) considered with a brief description of each :

A. High Pressure Gaseous (supercritical) Nitrogen --- SSIPFSS Reference Concept - The high pressure gaseous resupply/storage concept, or supercritical nitrogen resupply/storage concept as it is also called, is the simplest, most widely used method with which to store nitrogen for use as a gas. This concept was selected as the SSIPFSS Reference Concept for a multitude of reasons. Overall, since this type of system is less complex in terms of hardware, thermal conditioning required, and the method by which nitrogen is supplied to the distribution system, it is an attractive option. Furthermore, costs for hardware development and production will be lower as will be the costs associated with maintaining a less complex storage system. In contrast, the resulting high pressure vessels are larger and heavier in mass than their cryogenic tank counterparts because they are maintained at higher pressures, thus requiring larger and thicker pressure vessel designs. Higher operating costs may outweigh savings due to the design's simplicity. Figure 3.7-2 illustrates this concept in relation to all of the necessary hardware requirements.

Table 3.7-1 Integrated Nitrogen System User Fluid Requirements (IOC)

FLUID REQUIRED SYSTEM INTERFACE	QUANTITY (LBM/90 DAYS)*	REMARKS
ECLSS	412[8]	- Continuous supply to ECLSS Distribution Subsystem
IWS	27[16]	- Potable water tank pressurization
IWFS	TBD	- Waste water pressurization
USL Module	99.1[16]	- Experimental use
JEM Module	13.5[5]	- Experimental use
Columbus Module	13.5***	- Experimental use
Airlock Repressurization	67[8]	- Airlock loss makeup (EVA days)
Hyperbaric Airlock Pressurization	274****[19]	- Emergency airlock press. (6 atm)
Module Repressurization	353****[19]	- Repress. of repaired module
Skip Cycle (Contingency)**	269	- 45 day normal user requirements
USL Module (cooling LN2)	608[16]	- cooling purposes for experiments in USL

* 90 day resupply requirements

** Requirements for normal operations if resupply missed (limited experiment nitrogen)

*** Groundruled equivalent to JEM (SSIPFSS Program)

**** Based on best available estimate from Martin Marietta Space Station team (these figures are similar to values in the reference document)

Table 3.7-2 Integrated Nitrogen System Fluid Storage Requirements (IOC)

SUBSYSTEM	REQUIRED FLUID QUANTITY (LBM/90 DAYS)	REMARKS
Supply Subsystem	632 ±	- Supplies normal GN_2 user requirements - Two pallet interface locations - Second pallet interface for layover or for storage subsystem transfer - Only one primary supply pallet utilized to supply normal user requirements
	608±	- LN2 supplied as independent dewar for cooling in USL only
Contingency Storage Subsystem	896 ±	- Two redundant pallets isolated from one another - high pressure gas delivery - Requirements for emergency use only - HAL pressurization - module repressurization - skipped cycle (contingencies) - cabin atmospheric control - experimental use - Resupplied by Supply Subsystem - blowdown transfer - compressed transfer

± variation in the exact resupply quantity

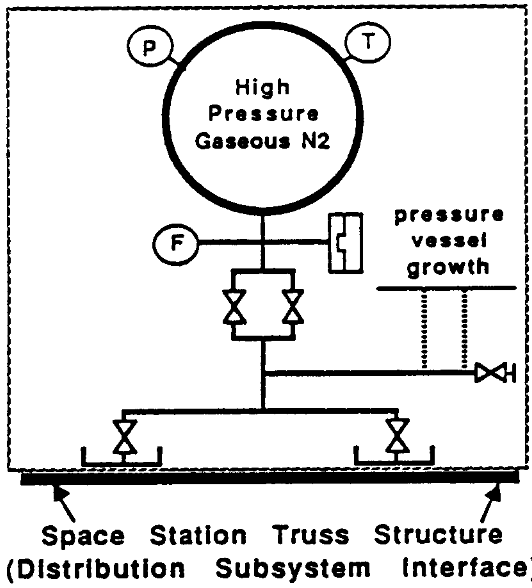

Figure 3.7-2 High Pressure Gaseous Nitrogen Resupply/Storage Concept

B. Cryogenic Supercritical Nitrogen --- Alternate Concept 1 - Another method of resupply and storage, termed the cryogenic supercritical approach, possesses unique characteristics of its own. Nitrogen is initially brought up as a cryogenic supercritical fluid, possessing properties of a cryogenic fluid, yet maintained at a constant high pressure above the critical pressure of nitrogen (493 psia). Below the critical pressure, the nitrogen would condense to a liquid, creating fluid management problems. By maintaining the nitrogen at cryogenic temperatures and at a constant pressure above the critical pressure, the fluid possesses some of the properties of liquid, but is uniform in its mixture and fills the tank volume as would a gas. Since it is neither a liquid or a gas in nature, it is termed a dense fluid. The high pressure allows for a blowdown supply, precluding the need for liquid pumps. As the fluid is depleted, the specific volume of the fluid increases, which in turn increases the amount of conditioning required to sustain the supercritical pressure. Tank conditioning is accomplished when some of the fluid from the pressure vessel is heated and recirculated (with heaters and recirculation pumps) back into the tank to maintain the pressure at an operating level above the critical pressure. Through the process of continually heating the tank to maintain pressure, the tank temperature may increase to unnecessarily high levels at the expense of a great deal of heater power. The system developed here only allows the temperature to extend to nominal delivery conditions of 70°F from which it is blown down as a high pressure gas at constant temperature. Such a system could expel nitrogen as a gas when the tank temperature exceeds the critical temperature of nitrogen (227°R). In this manner, the need for large amounts of power to maintain critical tank conditions could be eliminated and only a minimal amount of power would be required for heating the fluid to maintain user temperatures.

The cryogenic supercritical resupply/storage technique has advantages and disadvantages inherent in its design and implementation. The primary advantage is that this method allows the resupply of a larger mass fraction of nitrogen while allowing for supply blowdown. On the other hand,

cryogenic supercritical pressure vessel designs are still in development stages even though they have been applied to and qualified for specific uses; i.e. the shuttle PRSA tanks. This type of system will require further technology development and test qualification for its specific application on the Space Station. Another factor that disputes the practicality of such a system is the quantity of hardware necessary to condition the fluid in the tank and for nitrogen delivery to the user interfaces. This includes heaters both for tank heating and for user fluid heating. The delivery heater is really only necessary in the early stages of storage when the fluid is cryogenic. A fluid recirculator pump and internal tank mixer is also required to establish a homogeneous fluid mixture within the vessel. This system is much lighter in weight than the high pressure gas concept even when considering the number of different types of components it is comprised of. Figure 3.7-3 illustrates this concept in detail. Shown is only a single pressure vessel although the capability exists with which to add additional vessels to the pallet as growth concerns dictate. As additional cryo-supercritical pressure vessels are added to the pallet system, the conditioning hardware required by each is added, or at least a redundant set of conditioning hardware for overlapped use of more than one supply vessel when the transition is being made from one tank to another.

C. Subcritical Liquid Nitrogen --- Alternate Concept 2 - The last of three options proposed as candidate nitrogen resupply/storage system concepts is the subcritical liquid or liquid nitrogen technique. In this concept, nitrogen is brought up as a saturated cryogenic liquid, trapped by a liquid acquisition device and pumped out of the tank to the appropriate pressure and heated to the desired temperature for use. A pump and a heater are needed for the delivery conditioning process. A tank pressurization loop is incorporated into the concept design, functioning to provide a net positive pressure head on the fluid system for acquisition and pumping. This may be either an autogenous system where a small portion of the fluid expelled from the tank is heated and rerouted back into the tank, similar to the process used for tank conditioning of the cryogenic-supercritical system, or a system utilizing a pressurized helium source for liquid pressurization. Figure 3.7-4 illustrates this supply subsystem concept with the autogenous pressurization system. The system using helium for tank pressurization is shown in Figure 3.7-5. Note that the system with helium pressurization is the most hardware intensive of the supply subsystem options, similar to the cryogenic-supercritical concept. It is important to mention that a high degree of expulsion efficiency is attained from this system in addition to the advantage of bringing up the lightest supply subsystem with the largest fluid resupply mass fraction.

The subcritical liquid system is severely limited in its performance due to many different factors. First and foremost, cryogenic liquid tanks of this nature have not been able to effectively vent themselves in a low-g environment, posing operational limitations on the system. A possible solution to the venting problem might be to incorporate a thermodynamic vent system (TVS) with a tank heat exchanger of sorts, but this adds to the hardware and fluid requirements, and to the implications of venting or recycling cooling fluid. The autogenous pressurization system will inevitably result in tank heating over time, especially over the long time period between resupply missions, consequently requiring higher tank pressures for liquid acquisition and pumping. Although the helium pressurization system will alleviate high pressure and high temperature conditions in the tank, it may contaminate the stored nitrogen and adds to the hardware complexity of the resupply pallet and the supply subsystem.

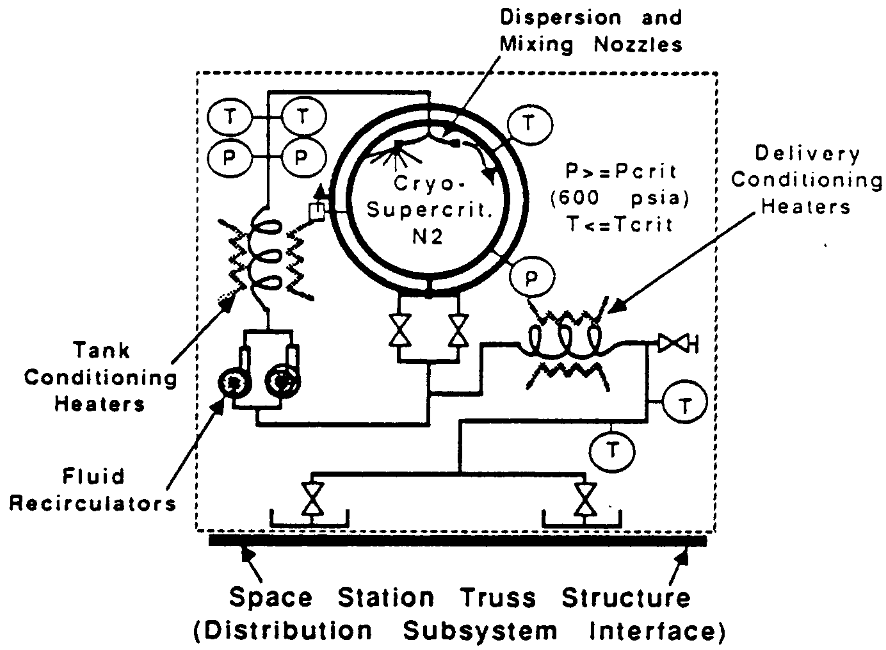

Figure 3.7-3 Cryogenic Supercritical Nitrogen Resupply/Storage Concept

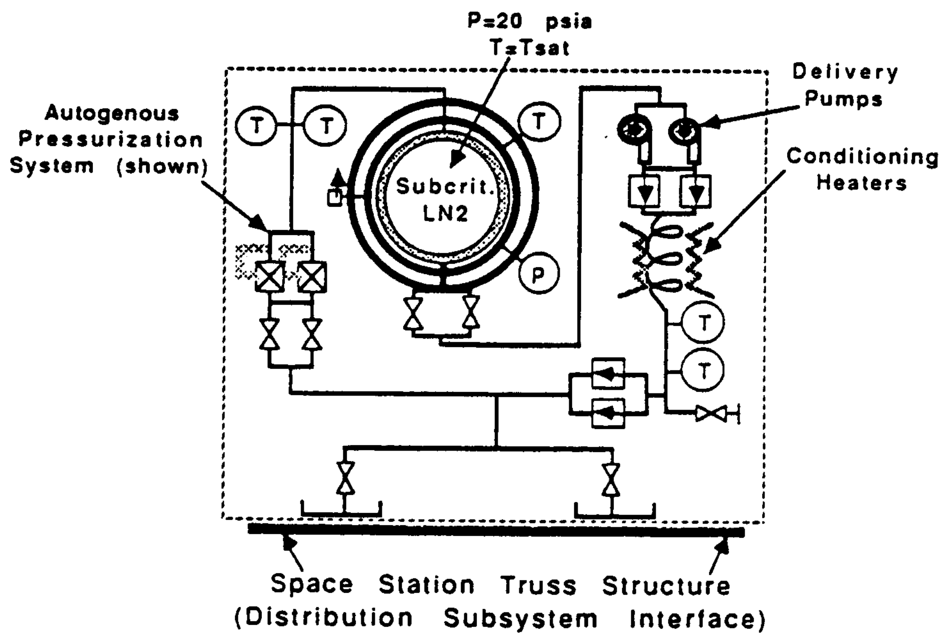

Figure 3.7-4 Subcritical Liquid Nitrogen Resupply/Storage Concept (Autogenous Pressurization)

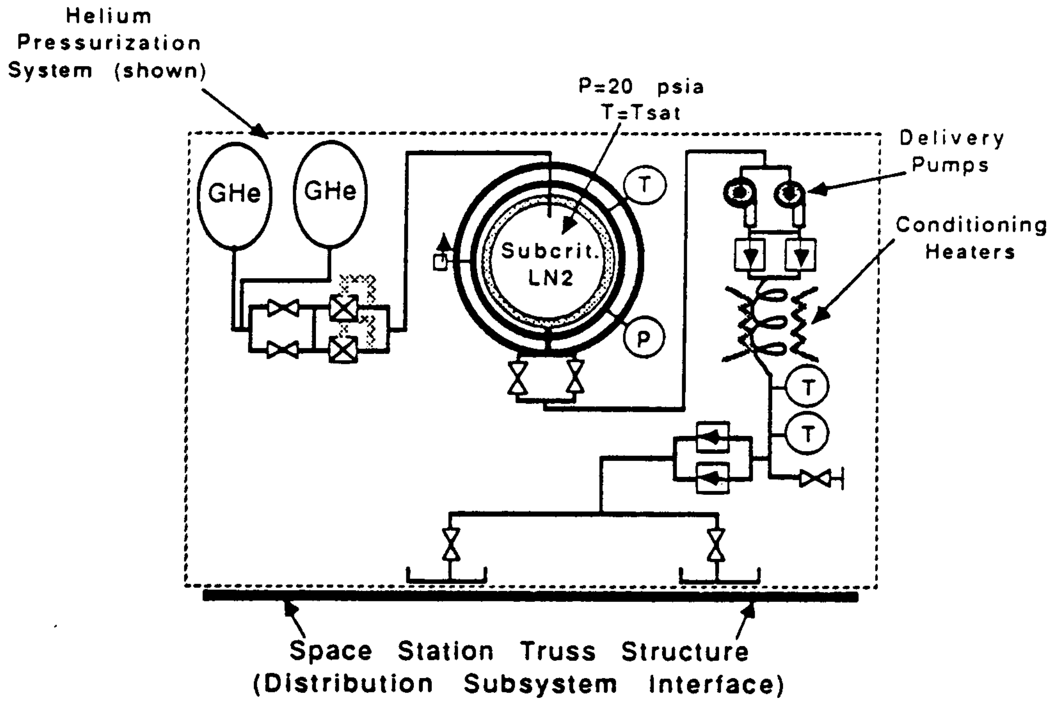

Figure 3.7-5 Subcritical Liquid Nitrogen Resupply/Storage Concept (Helium Pressurization)

3.7.6 INS Potential Candidate Configurations and Options

A series of integrated nitrogen system candidates as they relate to commonality and integration issues have been developed. All of the candidates developed are listed in Table 3.7-3 with brief descriptions of each. These options are presented in detail in EP 2.4, the "Fluids Management Systems Databook."

There are a total of four candidate gaseous nitrogen configurations comprised of many options. In this report, the terms *configuration* and *option* are used interchangeably here since options are different versions of the same general configuration, only constituted by slight changes in the hardware or operation of a configuration. Configuration 1 is the fully integrated INS that uses a high pressure gas (supercritical) resupply/storage concept for the supply subsystem (Reference Concept, Section 3.7.5.1 A., Figure 3.7-2). A total of four options of this configuration have been developed (Options 1A-1D). Configuration 2 is the fully integrated INS that uses a cryogenic-supercritical nitrogen resupply/storage concept (Alternate Resupply/Storage Concept 1, Section 3.7.5.1 B., Figure 3.7-3) for the supply subsystem. Six options of this configuration were developed for evaluation (Options 2A-2F). The last of the fully integrated gaseous configurations resupplies nitrogen as a subcritical liquid for the supply subsystem (Alternate Resupply/Storage Concept 2, Section 3.7.5.1 C., Figures 3.7-4 and 3.7-5). The subcritical liquid concept was evaluated because it was felt that its credibility should be investigated. Only a single option of this configuration was developed for evaluation (Configuration 3, Option 3). The last configuration, Configuration 4, is the partially integrated system which is comprised of a dedicated fluids rack for the experiments and a fluids pallet for the ECLSS system and other users. Eight options of this configuration were developed for evaluation (Options 4A-4H). Nitrogen is brought up as a high pressure gas in two different resupply units, one a fluids rack for experiments and the other a fluids pallet for the ECLSS and other users.

Sizes, weights, power, and interface specifications of the components associated with each INS option were determined and presented in Table 3.7-3. The methodology behind the determination of these system sizes and specifications is also presented in the EP 2.4 document.

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Table 3.7-3 INS Configuration Matrix with Specifications

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INS Supply, Storage, and Delivery Hardware Inputs to Integrated Cost Model

	Config. # (Option #)	Description of Configuration (Option)	Type of System	Resupply/Supply Subsystem Parameters: # Supply Tanks	Tank Volume-ft^3	Tank Size, diameter -ft	Tank Weight -lbm	Nitrogen Resupply Qty. -lbm/90 days	User Qty. of Nitrogen -lbm/90 days	Deorbit Nitrogen -lbm/90 days	Tank System Weight-lbm*	# Storage Tanks	Power Consuming Nitrogen Component Parameters**: Compressors Peak Power-kW	Compressors Energy -kW-hr/90 days	Pumps Peak Power-W	Pumps Energy -kW-hr/90 days	Heaters Peak Power-kW	Heaters Energy -kW-hr/90 days	Total Energy Required -kW-hr/90 day***
1	1A	3,500 psia high pressure gas supply, no delivery compressors, transfer compressors required for Pstor > 3,000 psia	Fully-Integrated gaseous N2	1	44.44	4.39	597	693	632	61	1290	1	NO no delivery compressors	None	N/A	--	N/A	—	0 +
2	1B	3,500 psia high pressure gas supply, with delivery compressors, transfer compressors required for Pstor > 3,000 psia	Fully-Integrated gaseous N2	1	40.97	4.28	551	639	632	7	1190	1	2.63 used for delivery to users	1.01	N/A	--	N/A	—	1.01 +
3	1C	8,000 psia high pressure gas supply, no delivery compressors, no transfer compressors required for Pstor up to 7,000 psia	Fully-Integrated gaseous N2	1	24.13	3.59	741	665	632	33	1406	1	NO no delivery compressors	None	N/A	—	N/A	—	0 +
4	1D	8,000 psia high pressure gas supply, with delivery compressors, no transfer compressors required for Pstor up to 7,000 psia	Fully-Integrated gaseous N2	1	23.07	3.53	709	636	632	4	1345	1	2.63 used for delivery to users	0.57	N/A	—	N/A	—	0.57 +
5	2A	530 psia cryo-supercritical supply, no delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.52	3.16	292	654.6	632	22.6	946.6	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.13 1.30	9.10 tank 19.73 delivery	28.83 +
6	2B	530 psia cryo-supercritical supply, with delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.01	3.13	284	634.5	632	2.5	918.5	1	2.63 used for delivery to users	0.4	Tank recirculator pumps - negligible power use		1.13 1.30	8.81 tank 19.12 delivery	28.33 +
7	2C	600 psia cryo-supercritical supply, no delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.39	3.15	290	654.4	632	22.4	944.4	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.13 1.30	9.24 tank 19.22 delivery	28.46 +
8	2D	600 psia cryo-supercritical supply, with delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	15.89	3.12	283	634.5	632	2.5	917.5	1	2.63 used for delivery to users	0.39	Tank recirculator pumps - negligible power use		1.13 1.30	8.96 tank 18.63 delivery	27.98 +
9	2E	1,000 psia cryo-supercritical supply, no delivery compressors, transfer compressors required for Pstor > 1,000 psia	Fully-Integrated cryogenic-supercritical N2	1	15.84	3.12	305	653.6	632	21.6	958.6	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.12 1.28	10.91 tank 16.78 delivery	27.69 +
10	2F	1,000 psia cryo-supercritical supply, with delivery compressors, transfer compressors required for Pstor > 1,000 psia	Fully-Integrated cryogenic-supercritical N2	1	15.38	3.09	298	634.4	632	2.4	932.4	1	2.63 used for delivery to users	0.38	Tank recirculator pumps - negligible power use		1.12 1.28	10.59 tank 16.29 delivery	27.26 +
11	3	20 psia subcritical LN2 supply, with delivery and transfer pumps, heaters used for tank and delivery nitrogen conditioning	Fully-Integrated subcritical liquid N2	1	13.65	3.00	256	645	632	13	901	1	NO no compressors at all	None	9.50 delivery, transfer pumps	0.20	1.58	33.3 tank and delivery	33.50 +
12	4A	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, transfer compressors required for Pstor > 3,000 psia, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 35.56	TBD 4.08	118 478	137 554.6	126 506	10.9 48.6	255 1032.6 1287.6	1	NO no delivery compressors	None	N/A	—	N/A	—	0 +
13	4B	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, no transfer compressors required, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 19.32	TBD 3.33	118 594	137 532.4	126 506	10.9 26.4	255 1126.4 1381.4	1	NO no delivery compressors	None	N/A	—	N/A	—	0 +
14	4C	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, transfer compressors required for Pstor > 3,000 psia, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 32.77	TBD 3.97	118 440	137 511.1	126 506	10.9 5.1	255 951.1 1206.1	1	2.63 used for delivery to users	0.81	N/A	—	N/A	—	0.81 +
15	4D	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, no transfer compressors required, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 18.46	TBD 3.28	118 567	137 508.9	126 506	10.9 2.9	255 1075.9 1330.9	1	2.63 used for delivery to users	0.46	N/A	—	N/A	—	0.46 +
16	4E	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, transfer compressors required for Pstor > 3,000 psia, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 35.56	TBD 4.08	118 478	137 554.6	126 506	10.9 48.6	255 1032.6 1287.6	1	NO no delivery compressors	None	N/A	—	N/A	—	0 +
17	4F	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, no transfer compressors required, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 19.32	TBD 3.33	118 594	137 532.4	126 506	10.9 26.4	255 1126.4 1381.4	1	NO no delivery compressors	None	N/A	--	N/A	—	0 +
18	4G	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, transfer compressors required for Pstor > 3,000 psia, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 32.77	TBD 3.97	118 440	137 511.1	126 506	10.9 5.1	255 951.1 1206.1	1	2.63 used for delivery to users	0.81	N/A	--	N/A	—	0.81 +
19	4H	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, no transfer compressors required, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 18.46	TBD 3.28	118 567	137 508.9	126 506	10.9 2.9	255 1075.9 1330.9	1	2.63 used for delivery to users	0.46	N/A	--	N/A	—	0.46 +

* Tank system weight includes the tank and nitrogen resupply weight

** Does not include transfer hardware specifications if components are required for the transfer of nitrogen to the Storage Subsystem

*** The '+' indicates additional energy is required to operate any Supply and Storage Subsystem tank heaters, and components for transfer to the Storage Subsystem in addition to the figures listed

3.7.7 Liquid Nitrogen Configuration Options

The development of a liquid nitrogen system to satisfy the user demands of LN_2 for cooling in the USL at IOC is of relatively major concern. Not only will the USL need nitrogen as a liquid, but virtually every laboratory or operation aboard the Space Station will eventually have some need for an LN_2 supply. The system designed to deliver liquid nitrogen to the USL users could either be integrated into one of the fully integrated N_2 systems for gaseous N_2 delivery or it could be an independently dedicated LN_2 system where LN_2 is brought up in liquid dewars for the sole purpose of supplying LN_2 for specific users in the USL. Although it is very much a possibility to integrate the gaseous and liquid N_2 requirements into a fully integrated system, lack of requirements definition as to the number of users, the N_2 use rates, and the length of plumbing, etc., may limit its practicality and render a locally dedicated system a more practical choice. It is therefore recommended that LN_2 be dedicated to the USL, at least for IOC.

All users of liquid nitrogen at IOC are currently aboard the USL. Even though the required quantity is relatively large (608 lbm every 90 days), a dedicated supply for the USL may be brought up via the PLC. This is justified since all LN_2 users are closely located to one another in the USL at IOC where single or multiple dedicated LN_2 dewars will handsomely accommodate the users. For these reasons, it is unnecessary to integrate the LN_2 system with other elements of the Space Station until further requirements definition dictates. Figure 3.7-6 illustrates how LN_2 dewars supply nitrogen as a liquid to USL users. The resupply system is composed of an LN_2 dewar with a pressurization system, and possible internal submersible pumps for LN_2 acquisition. This dewar resupply/supply system will interface with the USL at independent USL rack locations or through a vacuum-jacketed and insulated LN_2 distribution system. Examples of both options are shown in the figure.

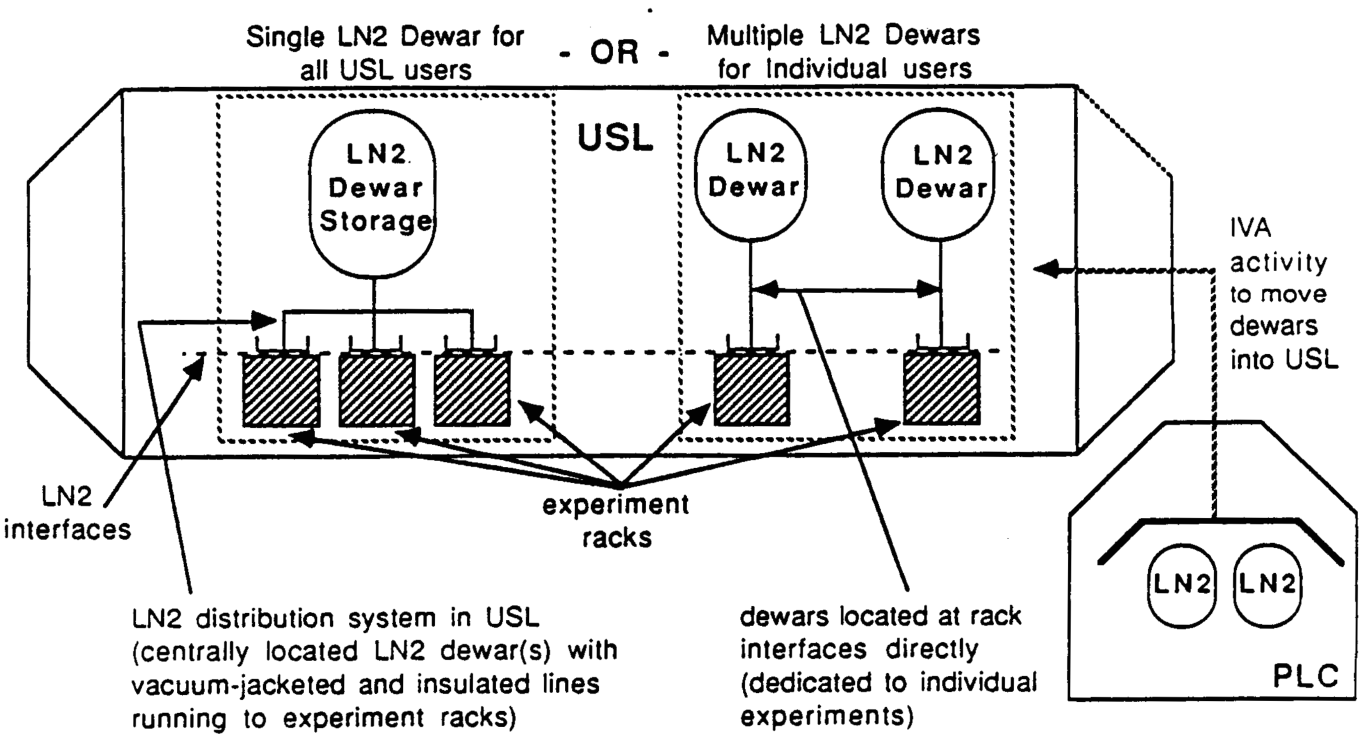

Figure 3.7-6 Supply of LN_2 Dewars for Liquid Nitrogen Requirements in the USL

3.7.8 INS Integrated Cost Model Assessment

An integrated cost model assessment was performed on the above candidate INS system configurations using the Integrated Cost Model developed under Task I of this program[3]. The results of the cost model study are presented. A Life Cycle Cost (LCC) analysis was conducted for purposes of identifying systems that are the lowest cost systems over a life cycle. Factors included in the cost study include recurring and non-recurring hardware and wraparound costs, initial fluid, launch, fluid resupply, spare parts, maintenance and deorbit (waste return) costs. All together, these cost items make up the overall IOC and operating costs of a system for a life cycle of 10 years.

The cost model assessment was used to evaluate the 19 gaseous INS options, each with three different storage subsystem options (total of 57 cases). The storage subsystem options included the 1,000 psia reference, the 3,000 psia system, and the 7,000 psia storage system. There are 4 options for high pressure gaseous resupply/storage (Options 1A-1D), 6 options for the cryo-supercritical resupply/storage configuration (Options 2A-2F), 1 option for subcritical liquid resupply/storage (Option 3), and 8 options for the dedicated high pressure gas configuration (Options 4A-4H). Of the 57 cases assessed, it was determined that the 3,000 psia storage subsystem option was the most cost effective for all INS options. The 5,000 psia minimum cost option was not evaluated with the overall systems and otherwise integrated with the INS options would constitute the lowest cost system.

The bottom line cost figures resulting from the cost model trade study suggest that a fully integrated system with a cryogenic-supercritical resupply/storage subsystem is the most attractive option from a life cycle cost standpoint. This most cost effective option (Option 2D) uses a 600 psia cryogenic-supercritical supply subsystem for resupply/storage of the nitrogen required by users. The percent cost savings for the life cycle is about 14% over that of the most cost effective high pressure gaseous option (Reference Configuration, Option 1B). Although the subcritical liquid configuration results in approximately the same life cycle cost as this cryo-supercritical option, the technology for storage, maintenance and acquisition of liquid nitrogen in a low-g environment is still in the stages of development and poses considerable technological risk for design, development, and implementation at IOC. For adequate relative comparison with other nitrogen system options, a realistic complexity factor would have to be placed on the subcritical liquid tanks in the cost model, however a representative figure can not be accurately substantiated. Therefore, the same complexity factor was applied to both the cryo-supercritical and subcritical liquid tanks. The actual cost of a subcritical liquid system should probably be greater than that suggested by the cost model. The IOC cost of high pressure gas systems (Options 1A-1D) was considerably less than the cryogenic options, however this cost was more than offset by the fact that high pressure gas vessels are larger and heavier, resulting in higher launch and thus operating costs of such a system. Due to the low hardware commonality of the dedicated INS options (Options 4A-4H), life cycle costs exceed the Reference Configuration (1B) by up to 23% and the overall cost optimum cryogenic-supercritical option (Option 2D) by up to 43%.

The Life Cycle Cost analysis results are summarized for the minimum cost options of each configuration (Options 1B, 2D, 3, 4C, and 4G). The LCC results for all options assessed is presented and described in detail in EP 2.4, "Fluid Management Systems Databook." Table 3.7-4 summarizes the overall life cycle cost figures for the minimum cost candidate INS options with the 3,000 psia storage subsystem option. The options are indicated as the configuration (option) number with an "(a)" suffix, indicating an INS with the 3,000 psia storage subsystem option. Table 3.7-5 lists the percent differences in LCC of the minimum cost INS options with the 3,000 psia storage subsystem from the Reference Configuration (1B). Figure 3.7-7 shows the costs of the lowest cost option for each configuration so that a direct comparison can be made between the

Table 3.7-4 Life Cycle Costs of Candidate Configurations (all Figures in $M)

Option #		Life Cycle Cost - $M		
		IOC*	Operating**	Total Cost***
1B (a)	**Refer.**	**55.62**	**318.4**	**374.0**
2D (a)		**63.66**	**256.8**	**320.5**
3 (a)		**60.20**	**258.0**	**318.2**
4C (a)		**67.85**	**333.7**	**401.5**
4G (a)		**67.60**	**337.7**	**405.3**

* includes component, wraparound, launch, initial propellant, and assembly costs
** includes propellant resupply, spare parts, maintenance, and deorbit costs
*** comprised of IOC and operating costs

Note : options in boldface type are the minimum cost options for each configuration

Table 3.7-5 Percent Difference in LCC from Reference Configuration (Configuration 1B (a))

Option #		Difference in LCC from Reference - %		
		IOC	Operating	Total Cost
1B (a)	**Refer.**	**0**	**0**	**0**
2D (a)		**14.4**	**-19.3**	**-14.3**
3 (a)		**8.23**	**-19.0**	**-14.9**
4C (a)		**22.0**	**4.81**	**7.36**
4G (a)		**21.5**	**6.06**	**8.37**

optimally cost effective options incorporating each supply subsystem concept. Figure 3.7-8 shows how the minimum cost options for each configuration vary from the Reference in terms of percent difference.

The life cycle cost may be reduced due to the possibility of recycling pure nitrogen already used by some of the interfaces. The nitrogen used by the IWS and IWFS interfaces for water and waste water pressurization in sealed bladder tanks may essentially be considered pure and recycled back into the INS distribution system. This nitrogen will have to be compressed back into the system, adapting well to systems that already use compressors for nitrogen management. Although the quantity of nitrogen that is still pure following use is small, recycling may reduce tankage sizes and launch quantities of nitrogen such that considerable cost savings may be realized over a life cycle.

3.7.9 Conclusions and Recommendations

Numerous candidate INS configurations comprising various levels of integration were developed over the course of this program. These candidates were developed to assess commonality and integration concerns involved with the selection of a nitrogen system for incorporation into the overall fluid management system for the Space Station. The INS configurations studied were developed by combining a series of technologically viable supply, storage, and distribution subsystem concepts for resupply, storage, transfer, conditioning, control and monitoring, and distribution of nitrogen. The configurations included three different resupply/storage methods and two levels of integration within the Space Station. For each configuration, numerous options were devised that were either operationally of configurationally different, but supplied gaseous nitrogen to the same users throughout the Space Station. Analyses based on integration criteria and cost

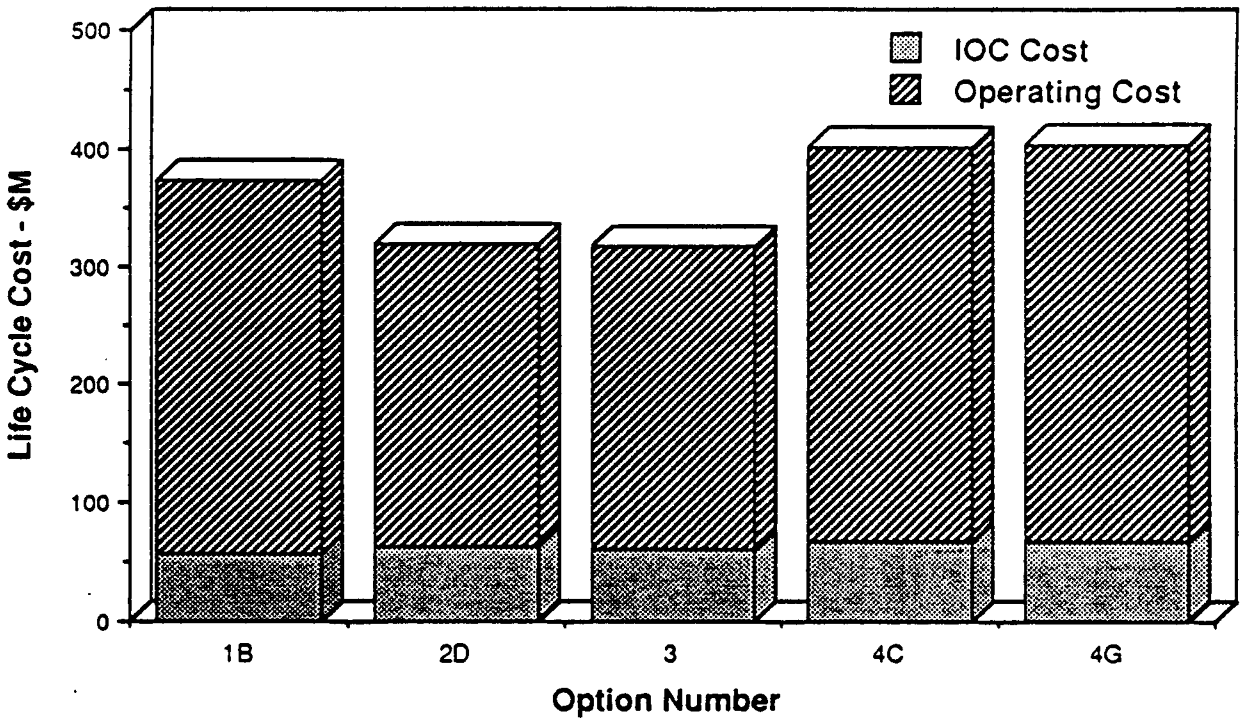

Figure 3.7-7 Life Cycle Costs of Minimum Cost Options

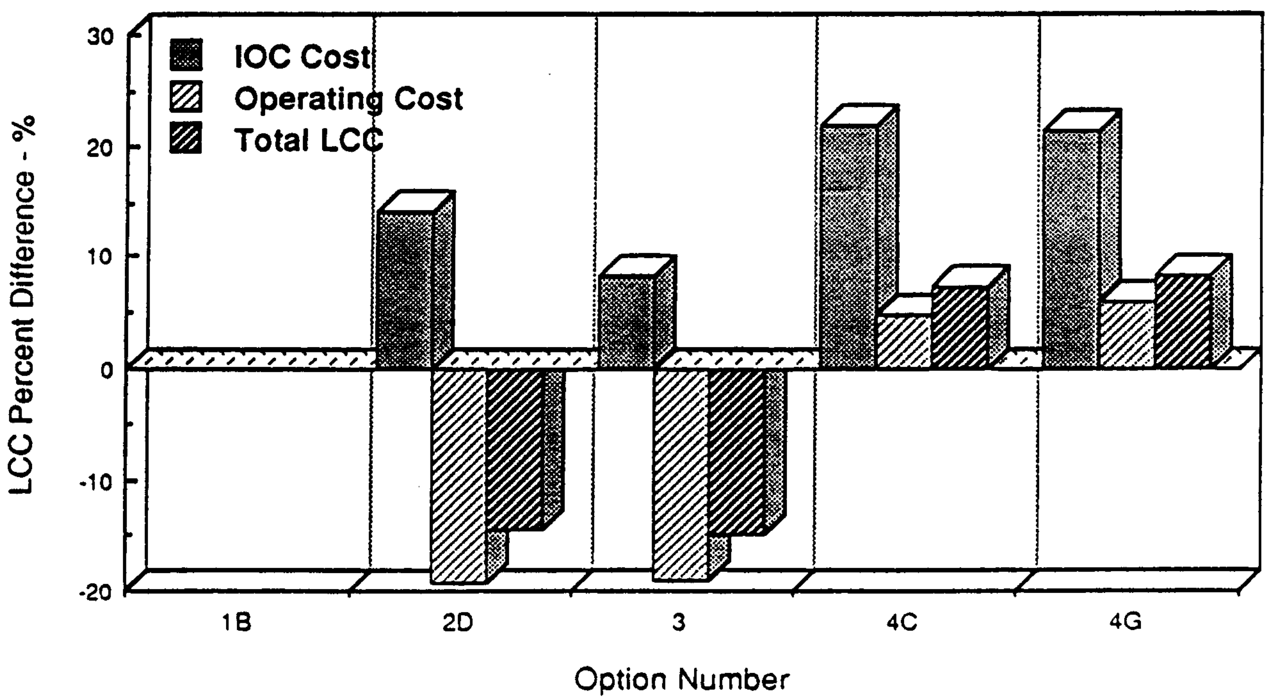

Figure 3.7-8 Percent Difference in LCC from Reference (Minimum Cost Options)

were performed to assess the credibility of each system option. Recommendations are made regarding the most feasible and cost effective system(s) for implementation into the Space Station fluid management system.

The levels of integration included full and partial (dedicated) integration of the gaseous systems and dedication of an independent liquid nitrogen system to USL experiment users. Integration is a very practical alternative for gaseous nitrogen users because the commonality advantage is enhanced by integrating the large number of users into a single fully integrated system. The types and numbers of components can be reduced as a higher level of integration is achieved. For all practical purposes, the liquid nitrogen system was evaluated as an independent system since it is difficult to see any merit in integrating the liquid and gaseous nitrogen users into a single totally integrated nitrogen system at this time. As currently defined, there are only a small number of LN_2 users confined to the USL module and they are in close proximity to one another. The simplest approach to supplying liquid nitrogen is to do so by resupplying liquid in dewars that are easily changed out of the USL and dedicated to the module experiments as a whole or to individual experiments. The complexity and cost involved with a totally integrated system that supplies both liquid and gaseous nitrogen from a common supply would be exhorbitant. Therefore, fully integrated gaseous N_2 and dedicated LN_2 systems are recommended as the nitrogen systems at IOC that are capable of satisfying all user demands and that optimize the commonality and cost factors.

The subcritical liquid nitrogen supply subsystem proved to be the most cost effective and required the least volume logistically for resupply. As the nitrogen resupply requirements increase, this approach will provide the greatest flexibility and integration potential with the USL and international liquid resupply systems. However, it is questionable whether or not the required technology to design and develop a liquid nitrogen system will be available in time for implementation on the Space Station at IOC. On-orbit experimentation will be required to demonstrate liquid nitrogen storage and transfer capabilities prior to design verification.

An alternative approach would be to provide a cryogenic-supercritical nitrogen supply/storage system with combination delivery/transfer compressors in the event that subcritical liquid technology is not available. The recommended operating pressure of this system is 600 psia, a level above the critical pressure of nitrogen, but not so high that it causes safety concerns or inefficient conditioning of N_2. The cryo-supercritical approach reduces the total life cycle costs of the INS by up to 14% over that of the Reference high pressure gas resupply concept, and is comparable to the cost of a subcritical liquid system. The IOC cost of the cryo-supercritical system is 14% more, but the operating costs, which are the major contributor to LCC, are about 19% less than the Reference Configuration. Compressors are used to improve the expulsion efficiency of supply subsystem pressure vessels and to effectively reduce the life cycle launch costs since less nitrogen has to be resupplied and deorbited. Compressors are also used to transfer N_2 for resupply of the contingency storage subsystem pressure vessels. This system reduces the logistic resupply requirements and provides flexibility for growth, similar to the subcritical liquid concept.

The high pressure contingency storage subsystem at 5,000 psia was the optimum option on the basis of cost; however, other options ranging in pressure from 2,000 to 8,000 psia were very close in cost and relatively similar in size. A system in this range is recommended for application to the gaseous nitrogen system selected for the Space Station. The actual operating pressure will be determined by the compressors' capability to transfer nitrogen to the storage subsystem. Below 2,000 psia, the system sizes, weights, and costs became very excessive. A high pressure contingency storage subsystem was chosen over options such as cryogenic storage due to its simplicity in design, and efficiency for potential long-term storage. The need for long-term nitrogen conditioning with gaseous nitrogen storage is nonexistent. A high pressure storage system will deliver nitrogen by blowdown at more adequate flowrates than a lower pressure system, and do so on demand without the need for intermediate steps such as gas compression. Furthermore, the resupply process is simplified following use of emergency or contingency

nitrogen since gas is readily transferred to the storage subsystem pressure vessels from the supply subsystem. A high pressure cryogenic supply is impractical and requires much fluid conditioning at high power consumption levels. Cryogenic storage vessels may not be efficiently resupplied on-board and instead will have to be replaced and traded out, requiring unnecessary and costly resupply activity.

3.8 INTEGRATED WASTE FLUID SYSTEM

3.8.1 Overview of the Integrated Waste Fluid System Assessment

The overall functions of the Integrated Waste Fluid System (IWFS) are to collect and store waste gases and waste water discarded by the Station elements for use in resistojet venting. This is a very complex system because it requires the transfer, storage, and conditioning of the waste effluents and the control and monitoring of each of these processes to ensure a safe environment for crew members and to ensure that contamination restrictions during on-orbit venting have been met.

The IWFS reference configuration used during this assessment is schematically presented in Figure 3.8-1[20]. This design concept consists of a central collection and storage system and a vacuum vent system. Waste effluents are initially transferred from the Station elements to the central collection and storage waste system through either a reducing line or oxidizer line, for waste gases, or a waste water line used exclusively for excess water. The transfer process for the gaseous systems occurs until the line pressure in the specific element reaches 0.25 torr at which time the central waste system is closed and the remaining effluents are evacuated to space through the vacuum vent line. This design concept also provides the collection of waste water from the experiments,

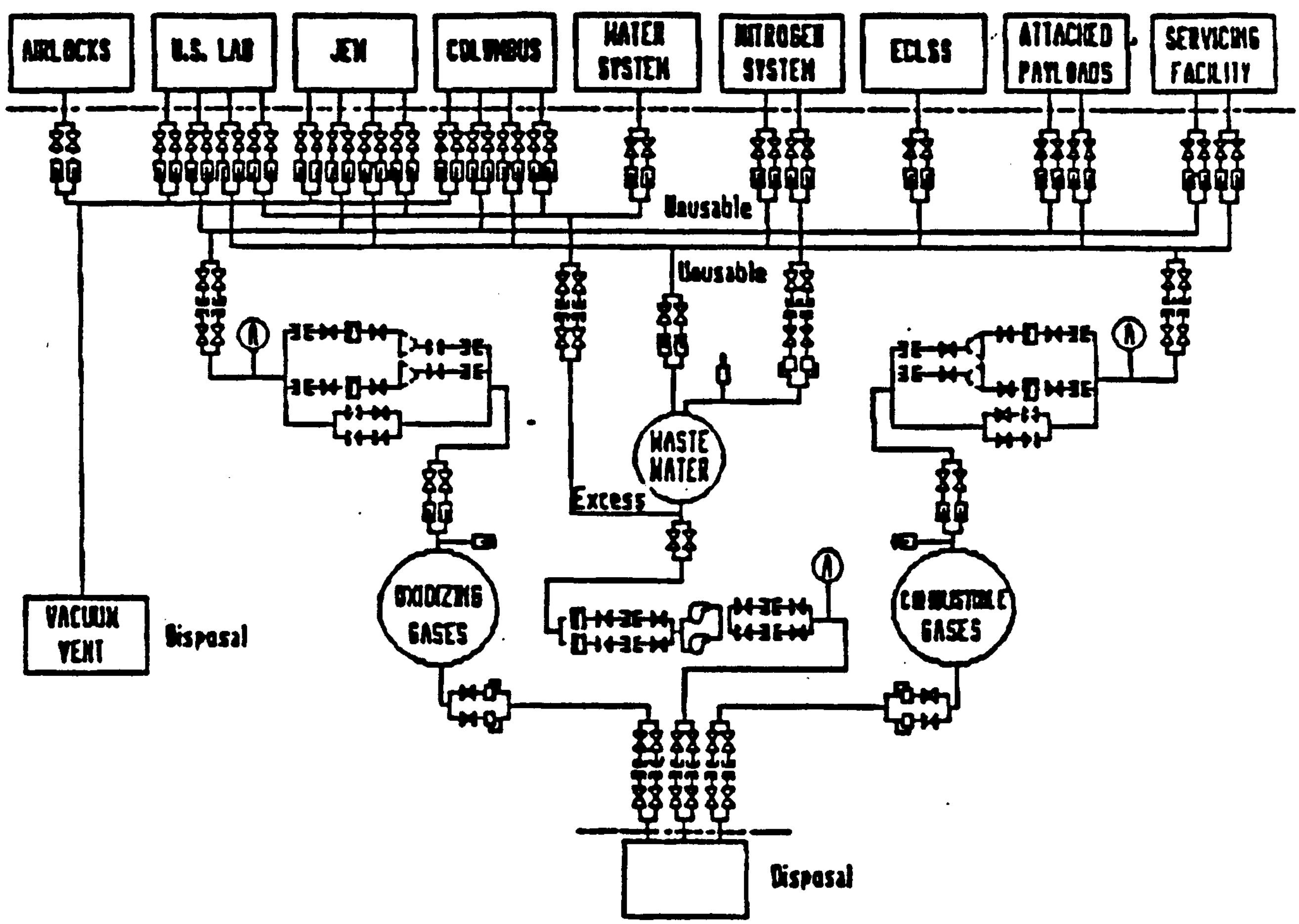

Figure 3.8-1 Integrated Waste Fluid System Reference Configuration

the Environmental Control and Life Support System, and the integrated water system. To meet long duration hold times imposed by the external environment criteria, the storage facility must accommodate a 15 day hold time before propulsively venting the effluents through resistojets. A detailed discussion of the IWFS reference configuration is provided in EP 2.1, the "Fluid Systems Configuration Databook."

As a means of assessing the IWFS reference configuration and developing alternate design configurations, an evalutation of the current fluid inventory was generated and resistojet venting restrictions were established. In conjunction, a thorough investigation of the contributing systems was performed to establish methods of collecting and conditioning waste effluents, and to identify methods for recycling waste effluents rather than disposing of them.

3.8.2 Integrated Waste Fluid System Inventory and Space Station Element Contributors

Space Station elements contributing to the Integrated Waste Fluid System include the four core Modules (United States Laboratory, Habitation, Japanese Experiment, and Columbus), the integrated nitrogen and water systems, Attached Payloads, environmental control and life support systems, and the fluids servicing facility. A careful inspection of each of the waste fluid contributors led to a revised functional schematic which assisted in assessing the current configuration and developing a recommended approach. The functional schematic is presented in Figure 3.8-2.

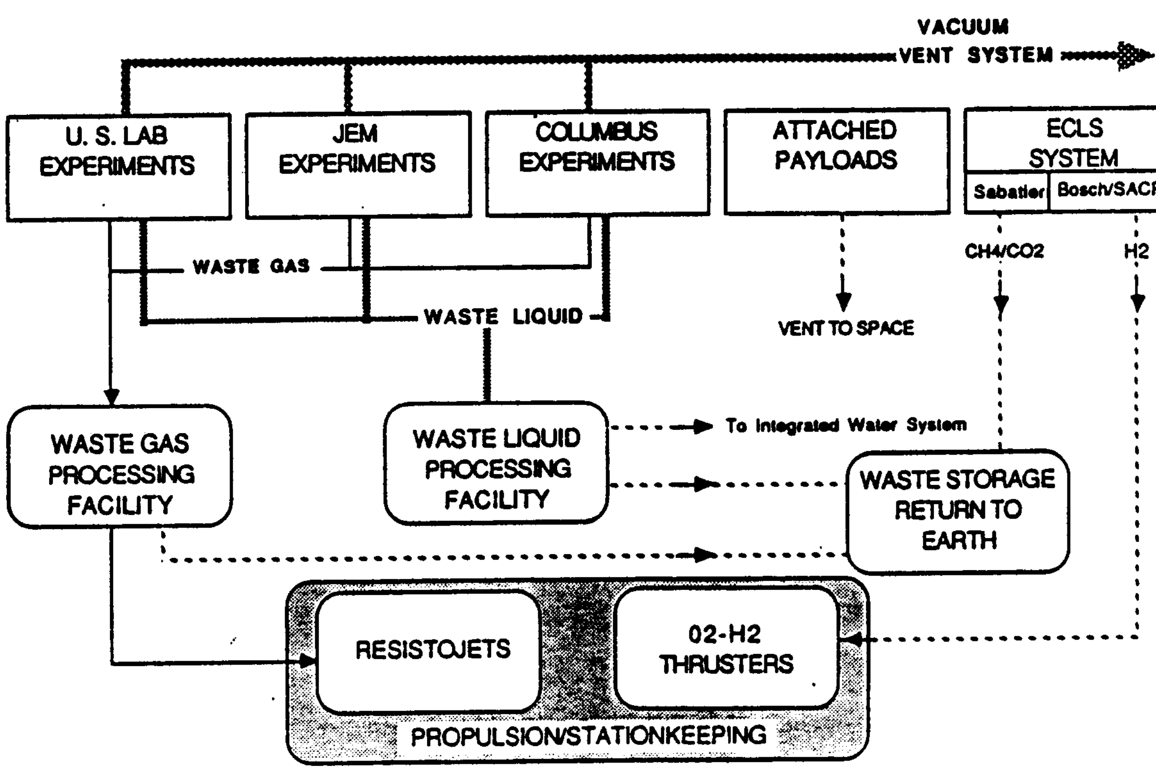

Figure 3.8-2 Integrated Waste Fluid System Functional Schematic

3.8.2.1 Experiment Fluids - Waste fluids contributed by the experiment modules were examined

by assessing the Martin Marietta and Boeing DR-O2 concepts for the Process Waste Handling System (PWHS) in the USL Module[17, 21] and by establishing fluid inventory data from the "Microgravity and Materials Processing Facility (MMPF) Study Data Release"[22] and Fluids Technical Interchange Panel information[19, 23]. The process waste handling systems are discussed in detail in EP 2.4, the "Fluids Management System Databook", along with the assessment of the experimental effluents transferred to the IWFS.

3.8.2.2 Waste Water - As defined in EP 2.1, the "Space Station Program Fluid Systems Configuration Databook", no experiments are presently transferring waste water to the IWFS. As a result, the only excess water defined is the potable water stored in the integrated water system. A water balance sensitivity analysis discussed in section 3.6 of this report indicated that in most instances additional water will be required to meet the high water demands of the crew, the experiments and the propulsion system, and that only a slight amount of water at any given time may be in excess. However, if there is an excess of potable water, the options are to transfer the water to the oxygen/hydrogen propulsion system or to transfer less water to the Integrated Water System from the potable water storage in the Space Shuttle fuel cells. Water can be used by the propulsion system either as steam through resistojets or as electrolysis produced oxygen and hydrogen burned in conventonal thrusters. The specific impulse of the resistojets using steam is 188 seconds as compared to a specific impulse of 380 seconds using the oxygen/hydrogen thrusters. Therefore, pound for pound, water used in the oxygen/hydrogen thrusters would provide better performance than it would in resistojets. As a result, the established reference configuration eliminated the use of waste water in the resistojets and the waste nitrogen used to perform the water transfer.

3.8.2.3 Environmental Control and Life Support System (ECLSS) - The type of waste effluents contributed to the IWFS from the ECLSS depend on the carbon reduction process used for life support functions. Gaseous hydrogen is the primary effluent from the Bosch carbon dioxide reduction process. This hydrogen contains traces of water vapor, however it can be desiccated and used in the oxygen/hydrogen thrusters. An additional amount of hydrogen reduces the mixture ratio and increases the thruster specific impulse. This results in a reduction of water required for propulsion and a reduction in overall life cycle costs. A cost analysis showed a greater cost advantage of using the hydrogen in the oxygen/hydrogen thrusters as compared to using it in the resistojets.

The primary effluent from the Sabatier CO_2 reduction process is a mixture of carbon dioxide and methane. Venting this mixture at high temperatures may result in carbon deposition in the resistojets. To prevent carbon deposition during venting, the resistojets may be required to operate at inefficiently low temperatures. An alternate method for preventing carbon deposition is to increase the amount of CO_2 and add steam to the mixture. Extensive testing will be required to verify the effectiveness of each of these methods.

A life cycle cost comparison was performed comparing the Bosch and Sabatier processes assuming that the Bosch hydrogen could be used in the oxygen/hydrogen thrusters, and the Sabatier carbon dioxide/methane mixture could be vented through resistojets at a specific impulse of 140 seconds. In all cases, the Bosch CO_2 reduction process proved to be the least expensive. The cost benefits were a direct result of a reduction in hardware and water resupply requirements, in addition to an overall improvement in the Space Station reboost performance gained by using hydrogen in the oxygen/hydrogen thrusters as compared to using the carbon dioxide/methane mixture in the resistojets. Another factor considered was that an IWFS integrated with a Bosch ECLSS system would require less developmental testing and would conceivably be less risky. Therefore, the recommended approach for integrating the ECLSS with the IWFS would be to incorporate the Bosch CO_2 reduction process or an advanced Sabatier process that would remove the hydrocarbons from the waste effluents prior to transfer to the IWFS.

3.8.2.4 Servicing Facility - No fluids were identified during the performance of this study.

3.8.2.5 Attached Payloads - Potential fluids available from the Attached Payloads were established from the NASA Lewis Study[24] and through telephone conversations with designated Attached Payload consultants[25-29]. Preliminary information indicated a substantial amount of carbon dioxide, nitrogen, helium, argon, and hydrogen available for resistojet venting. However, further discussions with the principal investigators of each of the identified experiments revealed that these fluids were not available for resistojet venting. In addition, discussions with the NASA Goddard personnel indicated that future Attached Payloads would also not be available for resistojet venting because of the need to perform vacuum venting to maintain the necessary pressures for instrument cooling and highly sentive operational performance. Therefore Attached Payload waste effluents were not included in the reference configuration. However, if effluents are identified in the future, they may be integrated into the recommended IWFS conceptual design with minor modifications.

3.8.3 Assumptions, ground rules, and Design Philosophy for a Recommended Approach for the Process Waste Handling System and the Integrated Waste Fluid System Design

To design a waste fluid management system, it was necessary to assume a set of experiments that would be run in the US Laboratory and to assume that similar experiments would be concurrently taking place in the JEM and Columbus modules. The fourteen experiments considered for these experiments are shown in Table 3.8-1.

An inspection of the experiment fluids indicated that some of the chemicals were not compatible with the IWFS. However, some of these chemicals can be reacted to produce by-products which can be safely processed by the IWFS. Some suggestions for reactions of this type are provided in section 3.8.4 of this report. Chemicals that are found to be hazardous and incompatible with the IWFS, and cannot be reacted to produce nonhazardous by-products are assumed to be stored within the experiment for return to Earth for disposal.

Table 3.8-1 Baseline Experiments

Acoustic Containerless Processing
Continuous Flow Electrophoresis
Directional Solidification
Droplet Burning
Electroepitaxy Crystal Growth
Electromagnetic Levitation
Free Surface Phenomena
Membrane Production Facility
Monodisperse Latex Spheres
Protein Crystal Growth
Solidification of Immiscible Alloys
Solid Surface Burning
Solution Crystal Growth
Vapor Phase Crystal Growth

For the purpose of this study, we assumed the experimenters to be responsible for verifying that waste effluents are compatible for transfer to the IWFS. This may mean that substitute effluents or waste storage within the experiment will be required. In addition, experimenters are assumed to provide temperature, pressure, and composition control before dumping their waste effluents.

The assumption that the experiments and their procedures preclude release of free liquids into the experiment facilities is also made. This requirement would probably come about naturally because of the necessity to use liquid acquisition systems to transfer fluids in low-gravity. An examination of the experiment configurations indicates this assumption to be true with the exception of the fluids glovebox and cutting and polishing facilities. Recommended approaches are provided to sustain this requirement of handling only gaseous wastes or liquid wastes at any given time. Particulates should be controlled also, and are assumed to be removed from both the liquid and gas lines through filtration. Both systems will be filtered as a routine matter to protect downstream components.

3.8.4 Assessment of Hazardous Chemicals and Potentially Hazardous Conditions in the US Laboratory

Table 3.8-2 lists the most hazardous chemicals used in the 14 baseline experiments. Some of these chemicals can be explosive under the proper conditions, some react quickly or violently, while others are highly toxic. From the list of experiments considered in this study, these chemicals were determined the most hazardous and, accordingly, these are the chemicals that should be very carefully monitored. Substitutes are recommended where possible.

Experiment details available at this time, are insufficient to determine whether there are serious problems associated with the usage and isolation of the atmosphere in the module. For example, acetylene is toxic and explosive in air, but only about 1.2×10^{-6} lbm will be used each 90 days. This may be used as a reference material, but the quantity is so low that the only concerns are in the storage area and nothing has been specified to indicate how or where it will be stored. Alternately, the quantity of beryllium is unspecified, but hazards to humans are very likely if the smallest of particulates escapes from any part of the experimental apparatus into the astronauts' atmosphere. In this case, it is already known that the strictest of measures will have to be employed for the astronauts' safety.

An important issue to emphasize is that the hazards are partially dictated by the experimental procedure. To minimize these hazards, the procedure for each experiment must be known and it must be reviewed by the experimenters, scientists and engineers not assigned to those experiments. This outside review is necessary to ensure that the experiment will take place as written, and to ensure that there are no unforeseen reactions within the experiment. A qualified review from IWFS personnel is also required to ensure compatibility between the chemicals, methods of dumping, and the IWFS components. The currently available information does not provide sufficient information to adequately evaluate the hazards.

Vaguely described chemicals in the experiments such as "solvents", "wash fluids", "monomers", "cleaning fluids", and "etchant solutions," require further definition and the concentrations of acids and bases must be described more accurately and completely to maintain the integrity of the IWFS. Furthermore, all chemicals must be specified before a dumping protocol can be established.

Particulate control within the USL appears to provide a very big challenge. The problem arises when samples have to be transferred from a work area such as the cutting and polishing module to an area not directly connected. Particles will be transferred in the air surrounding the sample and they will be transferred on the sample, its container, and its holder. Typical glovebox transfer chambers are evacuated and refilled with clean gases but this technique will not guarantee that particulates will be removed in the zero-g environment of the USL. Furthermore, particulates attached to the outermost surface of the sample or its container may not be removed by evacuation and refilling.

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Table 3.8-2 USL Hazardous Fluids Assessment

EXPERIMENT	HAZARDOUS MATERIAL	PHASE	MASS VENTED (LBM)	COMMENTS
CONTINUOUS FLOW ELECTROPHORESIS	SODIUM AZIDE	L,G	0.0055	EXPLOSIVE; RECOMMEND USING GLUTERALDEHYDE INSTEAD
DIRECTIONAL SOLIDIFICATION	MERCURY	P,L,G	UNCERTAIN	DEATH WITHIN DAYS OF CHRONIC EXPOSURE; ABSORBED AS A LIQUID OR VAPOR
	CADMIUM	P,G	UNCERTAIN	CARCINOGEN; MAY CAUSE BRONCHOPNEUMONIA. HIGH VAPOR PRESSURE FOR A METAL
	BERYLLIUM	P	UNCERTAIN	CARCINOGEN; DEATH MAY RESULT FROM VERY SHORT EXPOSURE TO VERY LOW CONCENTRATIONS
DROPLET BURNING (GAS CHROMATOGRAPH FACILITY)	ACETYLENE	G	0.0000012	TOXIC AND EXPLOSIVE; NEED TO CONSIDER QUANTITY, STORAGE AND METHOD OF USE
ELECTROEPITAXY	ARSENIC	P	UNCERTAIN	CARCINOGEN; MOST FORMS ARE TOXIC
SOLIDIFICATION OF IMMISCIBLE ALLOYS	BERYLLIUM	P	UNCERTAIN	CARCINOGEN; DEATH MAY RESULT FROM VERY SHORT EXPOSURE TO VERY LOW CONCENTRATIONS
SOLID SURFACE BURNING (GAS CHROMATOGRAPH FACILITY)	POTASSIUM	S	UNCERTAIN	EXTREMELY REACTIVE; INFLAMES WITH WATER
	ACETYLENE	G	0.0000012	TOXIC AND EXPLOSIVE; NEED TO CONSIDER QUANTITY, STORAGE AND METHOD OF USE
	LITHIUM	S	UNCERTAIN	REACTS SLOWLY WITH WATER TO PRODUCE H2; HAZARD IN CONTAINED AREA; RECOMMEND COMBINING WITH WATER FOLLOWED BY DILUTE HCl TO MAKE INTO A SALT (LiCl) AND H2 BEFORE ENTERING WASTE FLUID SYSTEM
	MAGNESIUM	P,S	UNCERTAIN	REACTS READILY WITH DILUTE ACIDS TO PRODUCE H2; HAZARD IN CONTAINED AREA; RECOMMEND COMBINING WITH DILUTE HCl TO MAKE INTO A SALT (MgCl2) AND H2 BEFORE ENTERING INTO WASTE FLUID SYSTEM
SOLUTION CRYSTAL GROWTH	SODIUM CHLORATE	P,L	UNCERTAIN	STRONG OXIDIZER; AVOID CONTACT WITH ORGANICS
	HYDROGEN PEROXIDE	L,G	UNCERTAIN	MAY DECOMPOSE VIOLENTLY IF TRACES OF IMPURITIES ARE PRESENT
	HYDROFLUORIC ACID	L,G	UNCERTAIN	POISONOUS, MAY CAUSE TOTAL DESTRUCTION OF EYES.
	NITRIC ACID	L,G	UNCERTAIN	REACTS VIOLENTLY WITH ALCOHOLS, CHARCOAL, ORGANIC REFUSE; USED TO MANUFACTURE EXPLOSIVES
	MERCURY-CADMIUM TELLURIDE	G,P	UNCERTAIN	MAY PRODUCE SAME HAZARDS AS THE ELEMENTS: DEATH WITHIN DAYS OF CHRONIC EXPOSURE; ABSORBED AS A LIQUID OR VAPOR; MAY CAUSE BRONCHONPNEUMONIA

l = liquid
g = gas
s = solid
p = particle

Portable transfer chambers present the same shortcoming. There remains a volume in these chambers which can become contaminated by particulates and this chamber is eventually opened to the USL atmosphere. There is no guarantee that the particulates will be removed, and therefore a concern exists that the particulates will be free to invade the USL environment and subsequently be inhaled by the astronauts working in the USL. If the number of particles is very small and they are not hazardous, this might be an acceptable approach. If the particles are beryllium, cadmium, or mercury, then this approach is not safe. Various methods using plastic bags as transfer containers have also been attempted. These systems have not been totally successful.

Another area in which particulate control must be addressed is during the removal of filters. The use of isolation valves that are removed with the filters eliminates the concern with particulates leaving the filter during change-out. However this approach is more costly in terms of dollars, weight, and complexity. Each application will need individual study.

The use of the glovebox indicates evacuation to 1 x 10^{-3} torr as an atmosphere cleaning mechanism. Normal rubber gloves would have to be much thicker to withstand this pressure differential and that would make them difficult to use. A fluids glovebox concept is discussed in

EP 2.4, the "Fluids Management System Databook" which overcomes this problem. A triple seal concept is also discussed in the databook, however, no description of how materials will be manipulated through these seals is available.

There are some specific hazards in the experiments associated with long storage time and cross reactions with other experiment effluents. The directional solidification experiment uses nitric and hydrochloric acids. Separately they attack many metals, but together, in the proper concentrations and proportions, they make aqua regia, which will attack nearly all metals. This acid could be particularly hazardous to valves, pumps, and other components.

The directional solidifcation and vapor phase crystal growth experiments use mercury fulminate, an extremely shock-sensitive explosive.

The continuous flow electrophoresis experiment lists sodium azide as a required chemical. If this is put into aqueous solution at pH less than 7, hydrazoic acid can be produced. This gas explodes violently even under volume expansion.

Some more general chemical hazards include hydrofluoric acid, which attacks glass and could present a hazardous condition over a long period of time, and freon which can result in an explosion on a fresh aluminum surface with a small shock. Creation of new surfaces (ampule breaking) can produce charge separation and result in a spark. The lower explosion limits of gases such as carbon monoxide, hydrogen, toluene, acetone, acetylene, and methane should be considered before these situations are finalized.

Cross-reactions between the experiment wastes need to be considered carefully in the dumping protocol. There are too many unknown chemicals to define the protocol in this study, but it must be established for the initial USL experiments and it must be reviewed whenever chemicals, concentrations, volumes, or temperatures are changed.

3.8.5 Venting Through Resistojets

3.8.5.1 Contamination Requirements/Restrictions/Considerations - Contamination control requirements were established based on the "Space Station External Contamination Control Requirements, JSC 30426[30]." The resistojet venting system will be required to operate only during non-quiescent periods (i.e., when the Shuttle is docked at the Space Station).

Contamination requirements set no limit on the temporary column density during non-quiescent periods. Column density is defined as the number of molecules per unit area that exist along the line of sight used by an experiment. Although no temporary column density limit is set, the contaminant deposition level on sensitive surfaces is limited to 4×10^{-7} g/cm^2-yr(8.2×10^{-7} lbm/ft^2-yr).

The types of waste materials that can be vented through the resistojet system are limited by considerations of safety, corrosion, and contamination by particles or droplets. Table 3.8-3 contains the list of materials that can be vented using the resistojet system. Table 3.8-4 is a list of some materials that should not be vented. Table 3.8-4 also contains comments about why these materials should not be vented.

3.8.5.2 Resistojet Venting Concerns - A concern with the resistojet venting system is possible contamination due to backflow from the resistojet nozzles. Calculations agree with Rockwell's results documented in "NASA Contractor Report 180832"[31] that the gases will be expanded close to the free molecular flow regime so that backflow will be slight. Experimental data from NASA/Lewis reported in AIAA-87-2121[32] show a plume density less than 5.6×10^{-5} molecules/cm^{-3} (9.2×10^{-6} molecules/in^3) at angles less than or equal to 85 degrees off axis for

distances less than or equal to 32 centimeters (1.05 ft) from the nozzle. This is for CO_2 at a chamber temperature of 300°K (80°F), chamber pressure 20 psia, and flow rate 0.2 g/s (4.4 x 10^{-4} lbm/s). The exit velocity of the CO_2 is estimated as 1984 m/s for a chamber temperature of 1400°C, (2552°F) and this velocity is used to estimate the mass flux rates which would occur in normal operation with this chamber temperature. On the reasonable assumption of an inverse square relationship between distance and density, the total incident mass flux at 8 meters (26 ft) from the nozzle and 85° off axis would be within the acceptable limit for deposited material on the Space Station. For the vented gases, the mass deposited on a surface is much less than the incident flux (except for cryogenic surfaces, where it can be nearly as large as incident flux). Also, backflow is expected to be much less than flow at 85° off axis.

Table 3.8-3 Materials Acceptable for Resistojet Venting

Helium
Neon
Argon
Krypton
Xenon
Nitrogen
Oxygen
Water Vapor
Carbon Dioxide

Table 3.8-4 Materials Not Acceptable for Venting Through Resistojets.

Material that Cannot be Vented (Partial List)	Comments
Particulates, droplets and fluids with low vapor pressure	- May result in deposition on exterior surfaces
Undefined materials (i.e., solvents)	- Constituents unknown
Mercury and materials containing mercury (such as HgCdTe)	- High toxicity, corrosive behavior toward aluminum alloys, and severe contamination effects on optics, plus relatively high vapor pressure (for a metal)
Halogens and ammonia	- Corrosive effect on grain stabilized platinum in resistojets
Freon	- Possible corrosion of the resistojet system at high temperatures
Organic compounds including	- Requires resistojet operation at inefficiently low temperatures to prevent carbon deposits - Proposed system removes organic compounds or converts them to ventable gases with the exception of the CO_2/CH_4 mixture from the ECLSS - Proposed system could use catalytic converter to combine mixture with oxygen to get carbon

From the above discussion, it is concluded that backflow from a properly designed and operated resistojet venting system will be insignificant, however, the data is preliminary and requires further investigation. Recent tests performed at Arnold Engineering Development Center[32] indicate more backflow from resistojets than the original NASA/Lewis experimental data show. These differences have not yet been resolved. Additional experimental work is being performed by R. Tacina at NASA/Lewis, and mathematical modeling is being performed by B. Riley of the University of Evansville under NASA contract.

Analytical data established through a Martin Marietta proprietary technique (IR&D Project D-08D, "Rocket Exhaust Contamination") agree with Rockwell's results in "NASA Contractor Report 180832" that the vented gases will not condense in the nozzle. No condensation of any of the vented gases is expected unless the gases impinge on a cryogenic surface.

The resistojets must be located downwind of any sensitive surfaces. Otherwise, molecules of vented material could collide with molecules of the natural atmosphere and be scattered (bounced) back to the sensitive surfaces. Preferably, resistojets should be located downwind of insensitive surfaces also, since contamination can potentially be transported between surfaces. Also, the resistojets should not be operated at higher pressures or lower temperatures than planned, or unacceptable backflow may occur.

3.8.6 Venting to Space Through the Vacuum Vent System

3.8.6.1 Contamination Requirements/Restrictions - The contamination control requirements are established in "Space Station External Contamination Control Requirements, JSC 30426[29]." The vacuum venting system will be required to operate during quiescent periods (i.e., when experiments requiring clean lines of sight may be in operation).

The contamination requirements set limits on the column density during quiescent periods. Column density is defined as the number of molecules per unit area that exist along the line of sight used by an experiment. The limits are 10^{11} molecules/cm^2 (6.5×10^{11} molecules/in^2) of infrared-active molecules and 10^{13} molecules/cm^2 (6.5×10^{13} molecules/in^2) each for O_2 for N_2, for H_2, for total noble gases, and for all other molecules combined. The grand total allowable is 5.0×10^{13} molecules/cm^2 (3.2×10^{14} molecules/in^2). Also, the contaminant deposition level on sensitive surfaces is limited to 4×10^{-7} g/cm^2-yr (8.2×10^{-7} lbm/ft^2-yr).

The types of materials that can be vented through the vacuum vent system are limited by considerations of safety, of corrosion, and of contamination by particles or droplets.

3.8.6.2 Reference Configuration for Vacuum Vent System Operation - The vacuum venting system is required to vent chambers of about one cubic meter (35 ft^3) volume each. The pressure in the chamber is 0.25 Torr (0.0048 psia) when the vent is opened and 0.001 Torr (1.9×10^{-5} psia) when the vent is closed again. The reference configuration of the vacuum vent line was assumed to be 120 feet long and 6 inches in diameter as a baseline for this study.

3.8.6.3 Flow Characterization in Vent Line

The vacuum vent system starts operating when the pressure in the experiment chamber reaches 0.25 Torr (0.0048 psia) and stops venting when the chamber pressure drops to 0.001 Torr (1.9×10^{-5} psia). At the lower pressures (about 0.004 Torr or 7.7×10^{-5} psia and less) the gas flow is "free molecular," meaning that the molecules move individually without having much influence on each other. At the higher pressures (up to 0.25 Torr or 0.0048 psia) transition flow occurs, meaning that the gas behaves as a coherent fluid but does not obey the same fluid flow laws which hold at high pressures. If the gas is allowed to vent as a coherent fluid from 0.25 Torr (0.0048 psia) to free space, the layer of gas flowing along the wall will turn sharply outward when it

reaches the end of the vent. This will cause a backflow toward the Space Station. If free molecular flow is maintained at the outer end of the vent tube, then the gas molecules will follow straight lines, and their paths will be within 90 degrees of the tube axis as they leave the vent tube.

3.8.6.4 Vent Line Sizing Based on Free Molecular Flow - The "plume" of gas from a vent tube is not as directional as that from a nozzle. To prevent significant backflow from occurring, the pressure at the end of the vent tube will have to be within the free-molecular range. The criterion that mean free path is greater than or equal to the tube radius requires pressures below 0.0044 Torr (7.7×10^{-5} psia) for a 6" diameter vent tube.

Quickly opening a full-size valve from chamber to vent could result in exceeding this pressure limit, causing backflow of vented gases to the Space Station. A properly sized opening for the flow control valve from the chamber to the vent tube would be one which passes vented gas into the tube at the same rate that gas at 0.004 Torr (7.7×10^{-5} psia) can exit the tube into a vacuum. Using data and equations from Dushman & Lafferty's book [33] for air flowing through orifices at 77°F (25°C), and assuming a 6" diameter vent, the safe size opening at the chamber end turns out to be about 3/8" (1 cm) diameter. As the chamber pressure drops, the opening can gradually be enlarged. The analysis used to estimate the opening size is conservative. Detailed analyses of transient flow for specific geometries might permit larger openings and, of course, the opening can gradually be enlarged as the chamber pressure decreases. Estimated vent times for various vent line configurations are presented in Table 3.8-5.

3.8.6.5 Vacuum Venting Concerns - There are many concerns associated with the present vacuum vent concepts including the following:

1) Any harmful materials accidentally released within a vacuum system during venting will enter the vent system.

2) It will be difficult to effectively prevent particles from entering the vent system. The larger particles vented may move slowly and thus may strike Space Station surfaces or intersect lines of sight of experiments requiring a clear optical field. (Slow moving particles were observed returning to Skylab surfaces after ejection from elsewhere on the Skylab.)

Approaches to particle removal include electrostatic precipitators and filtration. Electrostatic precipitators require some gas pressure, require periodic cleaning, and cannot remove all particles. Filters cause a pressure drop and the maximum pressure of 0.25 Torr is only 0.005 lbf/in^2.

3) With routine vacuum venting, there is no effective central knowledge or control over the materials vented. Many noxious, toxic, irritating, carcinogenic, and corrosive materials will be handled in the laboratories.

Table 3.8-5 Venting Times for Various Vent Line Sizes

Vent Line Diam (in)	Vent Line Length (feet)	Connection To Vent Line	Overall Conductivity (m^3/sec)	Overall Conductivity (ft^3/s)	Time Required to Vent (minutes)
2	120	Direct to vent line	0.000438	0.0155	210.
4	120	Direct to vent line	0.00359	0.127	26.
4	120	2 in. dia. 6 ft. long	0.00250	0.088	37.
6	120	Direct to vent line	0.01183	0.418	8.
6	120	2 in. dia., 6 ft. long	0.00503	0.178	18.

Note: Vent times calculated assuming free molecular flow (conservative)
- Conductivities are for free molecular flow
- 1 cubic meter (35 ft^3) of air at 25°C (77°F) vented from 0.25 Torr (0.0048 psia) to 0.001 Torr (1.9×10^{-5} psia).
- Conductivity in vent tube is proportional to cube of radius and inversely proportional to length

4) Excessive column densities persisting for tens of seconds may occur due to venting (depending upon the relative positions of the vent and the experiment line of sight, and upon the particular gas being vented). The initial venting rate for air through the 3/8" opening described in Section 3.8.6.4 above is 13 mg/s (2.9×10^{-5} lbm/s), and the chamber could initially contain about 390 mg (8.6×10^{-4} lbm) of air.

5) The impulse due to venting may be significant, since reduction of vibration, shock, and unwanted thrust is desirable. One cubic meter (35 ft^3) of air at 25°C (77°F) and 0.25 Torr (0.0048 psia) weighs 0.39 gram (8.6×10^{-4} lbm), and its sonic speed when vented is 346 m/s (1135 ft/s). The momentum is 0.135 kg-m/s or 0.135 N-s or 0.030 lbf-s for each venting.

6) Many chemicals to be used in the laboratories have not been defined. They must be characterized as to chemical and physical properties before plans can be made to control them. "Cleaning solutions" and "solvents" are not satisfactorily defined and cannot be allowed in the vacuum vent system.

3.8.6.6 Recommended Approach for High Quality Venting System

Concerns 1 through 5 above could be avoided by pumping the vacuum chamber all the way to 0.001 Torr (1.9×10^{-5} psia) using the regular vacuum pumps (which vent through the resistojets). The vacuum vent system could then be reserved for emergencies and optimized for emergency service.

Emergency venting must take place if an accidental chamber pressure increase threatens injury to personnel. Venting in an emergency mode must not take place otherwise, because unnecessary

and possibly severe contamination could result. Design of an emergency vent system would be more easily optimized if the system did not also have to vent routinely.

An emergency system could involve a panel (between chamber and vent line) which is mechanically pushed open (or possibly shattered) on instructions from a central microcomputer control which decides when a dangerous situation (such as rapid pressure increase) requires emergency venting. This decision process could be tailored to each experiment.

Emergency equipment and procedures must be provided in case of accidents involving particularly hazardous materials (examples: mineral acids, mercury, acetonitrile, beryllium, chlorine, iodine, mercury amalgams/alloys such as HgCdTe, and mercury compounds such as HgI_2).

Mercury and its compounds and alloys require special attention because of relatively high volatility, high toxicity, severe contamination effects on optics, and corrosive behavior toward aluminum alloys. Beryllium-containing materials also require special attention because their dusts, particulates, and chips small enough to be swallowed or inhaled are a serious toxicity and carcinogenicity hazard.

Precautions must be taken to prevent accidental release of materials into the venting system (e.g., from furnaces into thermally insulating vacuum spaces around them).

3.8.4 OPTIMIZED INTEGRATED WASTE FLUID MANAGEMENT CONFIGURATION

The recommended baseline for the Integrated Waste Fluid System (IWFS) is shown in Figure 3.8-3. A typical experiment rack, as shown in the upper left of the figure, will have three basic fluid interfaces with the IFWS: a waste liquid collection interface, a waste gas collection interface, and a vent system interface. Particulate filters are provided on the experiment side of these interfaces to protect the IWFS and its downstream components. Waste gases and liquids are removed from the experiment boxes via the respective waste collection systems. The vent line interface is provided both for emergency venting and for evacuation of the experiments to space vacuum.

The Waste Gas Collection system collects the waste gases from the experiments via two vacuum pumps in parallel. It is anticipated that small amounts of liquid may be collected in this system. Additional heat, for example, such as waste heat from the catalytic converter, may be required to keep these substances in the gas phase. An accumulator is provided to accommodate transients in the flowrate through the processing system, to accommodate variations in the flow from experiments, and to accommodate gases from the downstream storage tank which may need recycling.

Regenerable sorbent beds are used to remove most of the organic contaminants in the gas streams. Two of these beds are located in parallel to allow desorption of open bed as the other is adsorbing. Desorption is accomplished via a combination of reduced pressure and increased temperature. Initiation of the adsorb/desorb cycles is based on timing, with a monitor used to check for breakthrough of the beds. A third sorbent bed is located downstream of the first two beds as a precaution in the event of bed breakthrough.

An important issue to emphasize is that the hazards are partially dictated by the experimental procedure. To minimize these hazards, the procedure for each experiment must be known and it must be reviewed by the experimenters, scientists and engineers not assigned to those experiments. This outside review is necessary to ensure that the experiment will take place as written, and to ensure that there are no unforeseen reactions within the experiment. A qualified review from IWFS personnel is also required to ensure compatibility between the chemicals, methods of

C-2

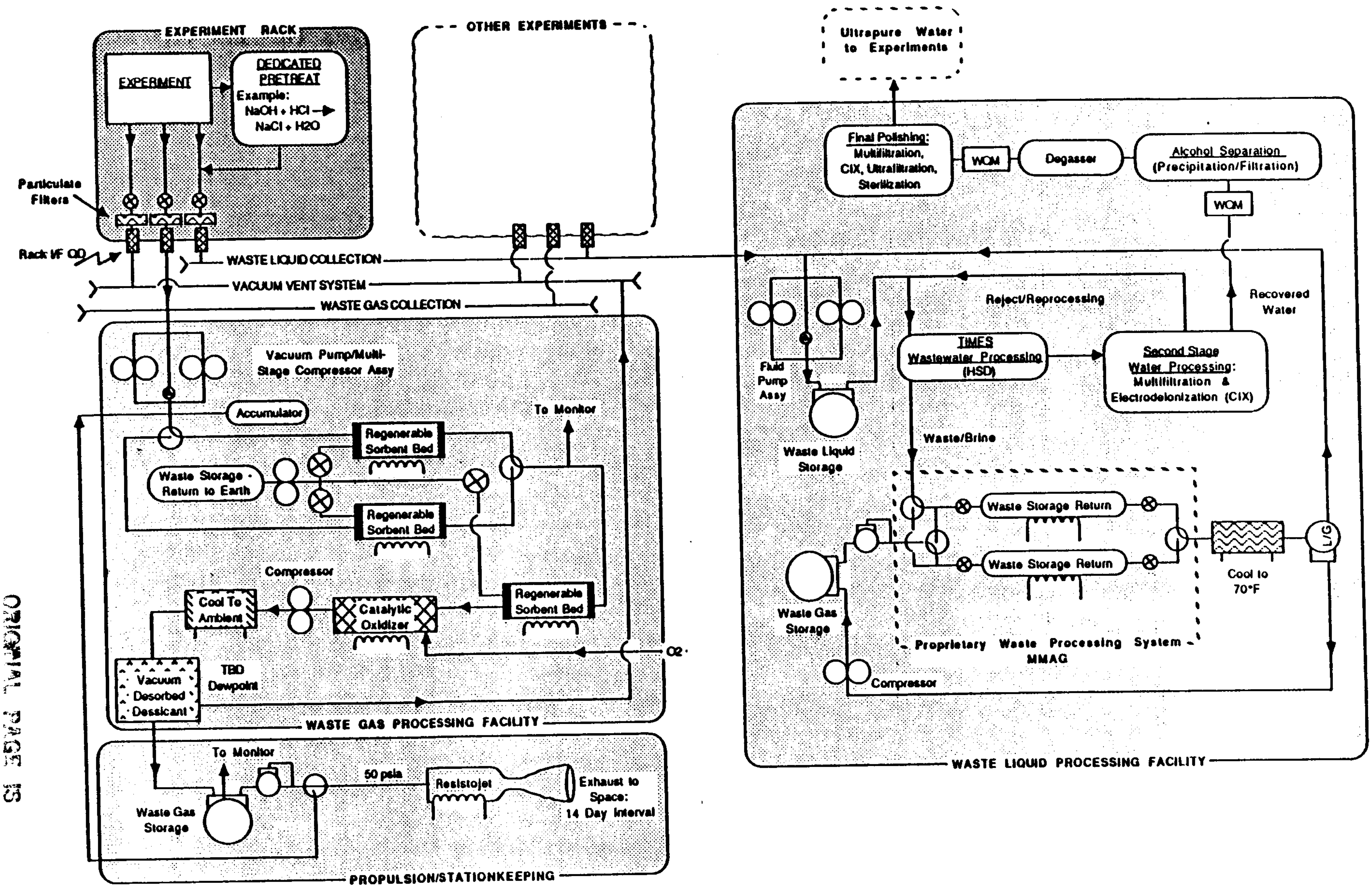

Figure 3.8-3 Recommended Configuration for the Integrated Waste Fluid System

sufficient information to adequately evaluate the hazards.

Vaguely described chemicals in the experiments such as "solvents", "wash fluids", "monomers", "cleaning fluids", and "etchant solutions," require further definition and the concentrations of acids and bases must be described more accurately and completely to maintain the integrity of the IWFS. Furthermore, all chemicals must be specified before a dumping protocol can be established.

Particulate control within the USL appears to provide a very big challenge. The problem arises when samples have to be transferred from a work area such as the cutting and polishing module to an area not directly connected. Particles will be transferred in the air surrounding the sample and they will be transferred on the sample, its container, and its holder. Typical glovebox transfer chambers are evacuated and refilled with clean gases but this technique will not guarantee that particulates will be removed in the zero-g environment of the USL. Furthermore, particulates attached to the outermost surface of the sample or its container may not be removed by evacuation and refilling.

After passing through the sorbent beds, the gas is passed through a catalytic oxidizer to remove any remaining contaminants which have not been captured by the sorbent beds. Typical catalysts for this type of application include Hopcalite and other palladium on alumina catalysts operating at 200° to 800°F. The catalytic oxidizer may not be required, depending on the effectiveness of contaminant removed from the gas stream.

A compressor, downstream of the catalytic oxidizer, raises the pressure of the gas to the required storage pressure. The gases are then cooled and passed through a desiccant to reduce the dewpoint to a temperature compatible with transfer to resistojets external to the Station. The desiccant is sized to require vacuum desorption only during periods when the external contamination requirements will not be violated.

The gases are stored in a storage tank where a final analysis is performed to insure compatibility of the gases with the resistojet and to calculate resistojet performance. If the gases fail these analyses, they are transferred via the three-way valve back to the accumulator at the inlet of the processing system.

The waste liquid system performs the function of recovering usable water from the waste liquid stream and minimizing wastes for return to Earth. A fluid pump assembly is used to collect the liquids from the experiments. A protocol will be established to preclude combining potentially incompatible liquids. The liquids are stored in a waste liquid storage tank, probably of the metal bellows variety, for flow normalization. The wastes then continue to the TIMES (Thermoelectric Integrated Membrane Evaporation Subsystem). The water recovered by the TIMES is further processed in a second-stage process using a combination of Multifiltration and Electrodeionization (or continuous ion exchange, CIX.[34]). Reject from this second stage processing is recycled back to the TIMES.

A water quality monitor analysis is performed to the recovered water to verify its purity. The product water then enters an alcohol separation process. This process uses the well-known iodoform reaction illustrated in Figure 3.8-4[35] . The products of this reaction are removed by a combination of ion exchange and filtration.

Following the alcohol removal process, the product water is degassed using a silicone membrane degassing technique[34] and then once again analyzed for purity. At this time, it is anticipated that conductivity will be the primary monitoring technique used.

A final polishing, consisting of multifiltration, CIX, ultrafiltration, and sterilization, will be performed. Sterilization can be accomplished by use of UV radiation or thermal cycling to 250°F.

The final product water will be acceptable for use in experiments.

The reject, or brine, from the TIMES processor will be further treated in a Martin Marietta proprietary process which incorporates a phase change of the liquid. The effluent is cooled to 70°F, which condenses the water, but leaves the Freons™ in a gas phase with any other

ETHANOL + NaOI $\longrightarrow$ $RCOO^-$ Na^+ + CHI3 (Iodoform)

$RCOO^-$ Na^+: *Removed by Ion Exchange Resin*

CHI3: *Yellow Precipitate (Melting Point 246°C) Removed by Filtration*

- This reaction also works with isopropal alcohol (IPA). Recommend substituting IPA for methanol.
- Other primary alcohols (i.e., methanol) do not react in this manner.
- This reaction will also remove ketones such as acetone and methyl-ethyl ketone (MEK).
- Note that the reaction goes to completion, thus removing all the alcohol.

Figure 3.8-4 Iodoform Reaction for Alcohol Removal

non-condensable gases. The water is collected with a phase separator and returned to the TIMES processor. The Freon™ and other gases are compressed and stored in a pressure vessel for intermediate storage and then released into the waste storage tanks containing the solid waste for return to Earth.

An in-depth discussion of the Integrated Waste Fluid System Components and supporting analyses for the design configuration is provided in EP 2.4, the "Fluid Management Systems Databook."

4.0 SPACE STATION INTEGRATED PROPULSION AND FLUIDS SYSTEM ASSESSMENT CONCLUSIONS AND RECOMMENDATIONS

Major benefits can be gained by integrating the Space Station propulsion and fluid systems beyond the Phase B Work Package definitions. These benefits include life cycle cost reductions and increased reliability through the use of common hardware within each of the systems and throughout the Space Station as a whole. The integration of these systems should propel the individual work package designs toward greater Space Station operational efficiency. However, time is critical, and fluid system requirements and fluid inventory data must be revised before the designs are set. A major effort should be focused on obtaining the necessary fluid information needed to support a cooperative design effort among individual work packages and fluid systems integrators..

An excellent example of the benefits gained through component commonality was discovered during the integrated oxygen/hydrogen system assessment. Reducing the number of electrolysis units from 8 to 4 and reducing the supporting equipment to perform the same functions resulted in a 10-year cost savings of $142 M, or 20%, over the present configuration.

An investigation of the supply, distribution and storage gas configurations showed that nearly all the gases could be supplied in common tanks with the same lines, valves and associated hardware used to construct the different systems. The major benefit of using the same hardware is a reduction in the number of spare parts required to be stored at the Station which would otherwise take up valuable space. The use of identical parts correlates to reductions in hardware development, qualification and test, launch, and overall life cycle costs.

Present configurations do not focus on the implementation of common hardware. For instance, liquid storage tanks are all being assessed individually. Different tanks are being recommended for the propulsion water system, the environmental control and life support system and the liquid nitrogen system. A common tank should be investigated to support all of these requirements, potentially an all metal tank system that provides liquid acquisition through capillary screens or vane devices. A tank that meets the constraining requirements of providing pyrogen free, potable water to the experiments and is capable of supplying liquid effluents in the future. At a minimum, the same tank should be used for storage of propulsion water and Environmental Control and Life Support System water. Research and developmental testing should begin now to provide that one tank that could meet all the necessary requirements for liquid storage on the Station and could support the fluid servicing facilities in the future.

Investigation of the fluid systems and associated requirements revealed a delicate balance between individual propulsion and fluid systems across work packages and a strong interdependence between all other fluid systems. Table 4.1-1 presents the parameters that are highly sensitive to changing Space Station requirements and the fluid systems that these parameters affect. A change form the initial food water content of 1.1 to 2.68 lbm/person/day would increase the water available for propulsion by 98%. Or, in the event that resistojets are unable to vent the CO_2/CH_4 mixture, the ECLSS may be driven to a Bosch or advanced Sabatier CO_2 reduction process to avoid large logistics requirements for deorbiting the waste effluents. This type of interdependency requires close coordination among USL and international experimenters, individual Work Package contractors, Attached Payload experimenters, resistojet developers, and operational working groups, including those associated with contamination, power, and microgravity requirements. To ensure that the integration of these systems propel the individual work packages, an independent team to continually assess the direction of the fluid systems designs should be initiated at NASA Level II Headquarters. In this was an unbiased assessment of the integrated fluid systems will be achieved.

Table 4.1-1 Propulsion and Fluid System Interdependency with the Space Station Design

SYSTEM	SENSITIVE PARAMETERS	EFFECT ON SPACE STATION DESIGN
INTEGRATED OXYGEN/ HYDROGEN SYSTEM (ECLSS AND PROPULSION)	• FOOD WATER CONTENT • CO2 REDUCTION PROCESS • RESISTOJET CAPABILITY	IWFS - DESIGN OF FLUID CONDITIONING COMPONENTSRESUPPLY PROPULSION - O2/H2 STORAGE TANKS REQUIRED FOR STATION KEEPING ADDITIONAL H2 OR CO2/CH4 MIXTURE AVAILABLE FOR IMPULSE SHUTTLE - RESUPPLY SCENARIO/ INTERFACE DESIGN LOG - VOLUME REQUIRED FOR RESUPPLY USL - WATER AVAILABE FOR EXPERIMENTS IWS - STORAGE CAPACITY/ DESIGN CONTINGENCIES
INTEGRATED NITROGEN SYSTEM (INS)	• EXPERIMENT REQUIREMENTS • SCARRING REQUIREMENTS FOR MMU, OMV AND SERVICING FACILITY • THERMAL ENVIRONMENTS	LOG - LOGISTICS RESUPPLY VOLUME INS - NITROGEN STORAGE AS LIQUID OR GAS MMU - EVA/IVA DESIGN REQUIREMENTS FOR MAINTENANCE INS - TANK DESIGN INS - SCARRING FOR GROWTH
GASEOUS RESUPPLY DISTRIBUTION SYSTEMS	• EXPERIMENT REQUIREMENTS	LOG - VOLUME REQUIRED FOR RESUPPLY LOG - NUMBER OF SPARE PARTS MMU - EVA/IVA MAINTENANCE PROCEDURES/ DESIGN REQUIREMENTS
INTEGRATED WATER SYSTEM (IWS)	• PROPULSION REQUIREMENTS • FOOD WATER CONTENT • CO2 REDUCTION PROCESS	IWS - LOCATION OF WATER STORAGE LOG - VOLUME REQUIRED FOR LOGISTICS RESUPPLY SHUTTLE - SHUTTLE RESUPPLY SCENARIO INS - VOLUME REQUIRED IN NITROGEN TANKS IWS - TANK/FLUID SYSTEM COMPONENTS
INTEGRATED WASTE FLUID SYSTEM (IWFS)	• VACUUM VENT CAPABILITY • RESISTOJET USE OF CH4/CO2 MIXTURE • INSUFFICIENT FLUIDS INVENTORY INFORMATION	ECLSS - USE OF SABATIER SYSTEM ECLSS - USE OF H2 FROM BOSCH SYSTEM PROPULSION - PROPULSION RQMTS/ SIZING FOR WATER STORAGE IWFS - SIZING FOR WASTE GASES IWFS - DESIGN OF COMPONENTS FOR WASTE CONDITIONING IWFS - INSTRUMENTATION FOR SAFETY AND INVENTORY IWFS - COMPRESSOR DESIGN JEM - FLUID CONDITIONING DESIGN PRIOR TO USE OF THE IWFS COLUMBUS - FLUID CONDITION DESIGN PRIOR TO USE OF THE IWFS ATTACHED PAYLOADS - EXPERIMENT SCENARIO FOR VIEWING/ VENTING CONSTRICTIONS

Based on the results of our study we recommend that the oxygen/hydrogen propulsion system be integrated with the environmental control and life support system and the experiment gas system to reduce life cycle costs. Implementing the Bosch CO_2 reduction process into the ECLSS is also recommended because it would assist in reducing life cycle costs, minimize technological risks, and provide the least complex method of waste disposal. A common tank is also recommended for the propulsion and environmental control support systems. An all metal tank would be the most desirable, however, developmental testing is required, and if an all metal tank is not available for use at IOC, a GRO tank outfitted with a bladder that is compatible with the ECLSS requirements may be suitable to meet the immediate requirements at IOC.Mounting the tanks internally in the Space Station nodes would be more desirable than externally mounted them because of meteroid shielding problems, the need for additional thermal conditioning and the high cost of EVA repairs as compared with IVA costs. However, space within the nodes is a valuable commodity and may not be available for use. Under the ground rules of this study the space required to support the propulsion water requirements would take approximately four double fluids racks.

The recommended approach for the resupply of nitrogen to the Station users is to provide a dedicated liquid nitrogen dewar for USL experiements and a fully integrated system for gaseous users at IOC. Study results indicate a subcritical liquid system is the most cost effective, however, this system may pose technological risks at IOC, and therefore an alternative would be to provide a cryogenic supercritical nitrogen supply system integrated for gaseous users at IOC. Technology is currently being developed for a subcritical liquid storage for use aboard the Space Station and is recommended for future evaluation. Studies have shown that this concept would be ideal for integrating Space Station liquid nitrogen users into a totally integrated system. The demand for liquid nitrogen is expected to increase drastically over the life of the station requiring prime consideration for a liquid nitrogen system for full operational capability and beyond.The subcritical liquid concept would accommodate this increased demand for liquid nitrogen as well as providing for gaseous nitrogen users.

The integrated waste fluid system is a major design driver of the performance of the Space Station. The operational flexibility of the IWFS will directly effect the operational efficiencies associated with on-orbit experimentation and the use of crew time. The recommended approach to the IWFS provides a feasible, safe method for waste disposal that provides for future growth and international integration. A major design concern with the recommended approach is the required development of on-orbit, long life compressors. Although the development associated with an on-orbit compressor would be extensive, it is a surmountable problem. Potential electrically motor driven, low speed, positive displacement type compressors are presently being investigated by industrial contractors.

To adequately size and verify the recommended integrated waste fluid system concept, all constituents including acid and base concentrations, cleaning solutions, monomers, and etching solutions must be adequately defined. Procedures for each experiment also need to be defined. After a revised waste fluid system inventory is established, individual effluents should be examined for hazardous conditions, and cross-reactions between effluents should be examined for special reactions and long exposure times. Experimenters requesting the use of hazardous fluids or fluids that are incompatible with the IWFS should be responsible for their isolation, containment, and disposal.

Vacuum venting concepts proposed in the Martin Marietta and Boeing Concepts result in the backflow of vented gases to the Space Station as the gas moves from a transition flow to a free molecular flow. Using vacuum pumps to bring the experiments to a condition of 0.001 torr would allow for emergency venting only and preclude problems associated with the control and monitoring of the vacuum vent line and of the release of particles that may interfere with external experiment viewing.

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